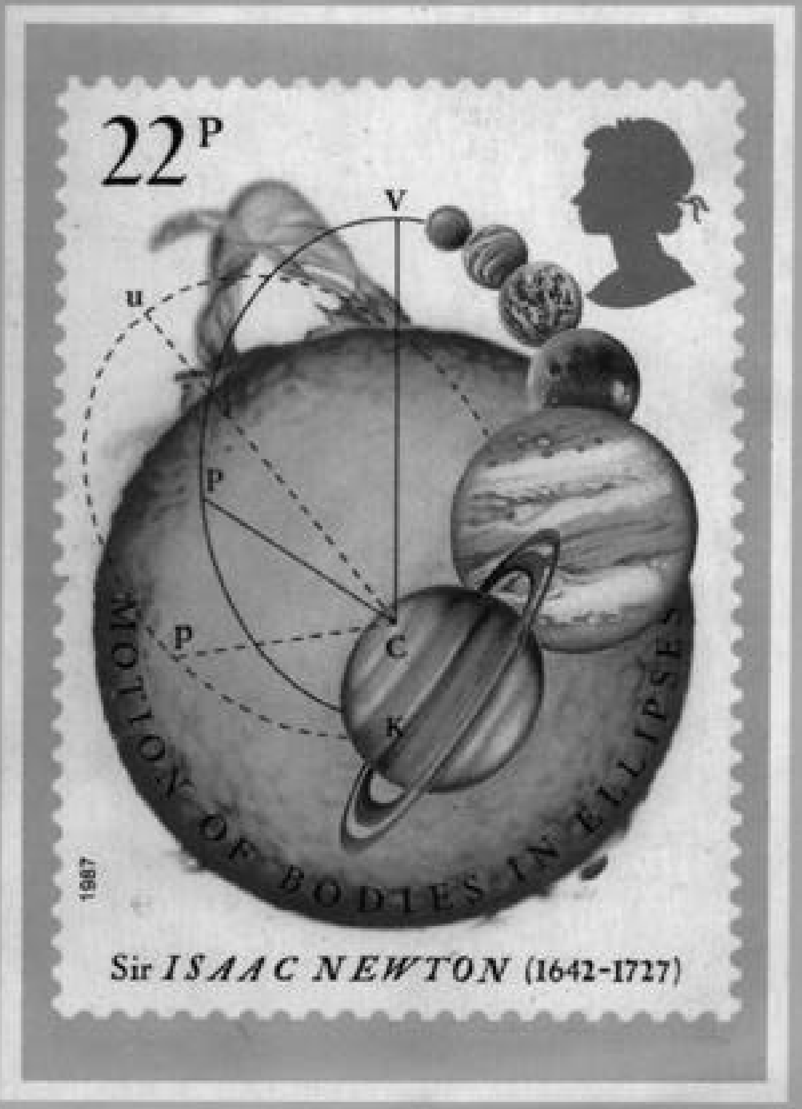
ICASE

EXPERIMENTS AND ACTIVITIES on the THREE LAWS OF DYNAMICS

A teacher resource book
commemorating the
300th anniversary of
Newton's Principia
1687 - 1987



ICASE

COMMEMORATIVE PUBLICATION

TEACHER RESOURCE NOTES

EXPERIMENTS AND ACTIVITIES
ON THE
THREE LAWS OF DYNAMICS

FOREWORD

It is a pleasure to commend this commemorative issue to science teachers around the world. Sir Isaac Newton made a unique contribution to the development of science and it is only fitting that his efforts be remembered in such a useful manner as a book of resource notes on the teaching of the three laws of motion.

I am pleased to note that the book addresses two important issues

a) the importance of experimental work in treatments involving Newton's ideas on dynamics - experiments that can be often carried out with the minimum of equipment

b) the importance in relating science within schools with the world outside, making dynamics very much part of life

I congratulate ICASE on its ability to put together such a book of international interest and I am sure teachers in all countries will be better able to appreciate the work of Newton in his famous **Principia** published 300 years ago.

Sir George Porter, P.R.S.
President,
The Royal Society

PREFACE

This booklet commemorates the three hundredth anniversary of Newton's "Philosophiae Naturalis Principia Mathematica" (first published in 1687) with a series of laboratory and home experiments illustrating the three laws of dynamics. It would, of course, have been possible to have chosen many other ways of commemorating such an important event and the teaching of theoretical mechanics and universal gravitation in a historical perspective. But there is the feeling that in many countries teachers do not give laboratory work the emphasis it deserves, either at primary or secondary school level and it is for this reason that this commemorative booklet is geared to experimental science.

The booklet is intended as a teacher resource, providing activities and experiments in dynamics. It has been compiled primarily for science teachers at the secondary level, but many of the activities suggested are also appropriate for work with children at the primary level, provided that teachers introduce the topics in a suitably modified manner.

There is a wealth of good material on dynamics; new and old journals and books, the manuals of well-known curriculum projects, etc. Making a choice from so many possibilities is not easy. The criteria used for this booklet was -

(i) the experiments and activities were not universally too well known

(ii) they were very meaningful from both a didactic and physics point of view.

In practice the material collated was chosen because it appeared less academic and more attractive to pupils.

The search for suitable materials turned out to be most interesting and rewarding. I was given the opportunity of discovering a world I had not before appreciated; the rich and fascinating world of the teaching of physics, as it was some decades ago. And it was at this point, when comparing the new didactics with the old that I grasped an essential feature of physics teaching of our times - the complexity of our task. In the older physics journals, such as the **School Science Review** of the 1940's, the problems being considered were almost all internal to physics, and the didactic aids referred to were very simple. Nowadays the problems are much more complex and I should like to elaborate a little on this.

It is becoming increasingly important for physics teachers to think about the wider perspectives of their subject when preparing lessons. In addition to the many problems traditionally associated with teaching physics - I shall call these the "standard" problems - there are several wider perspectives which cannot be ignored by any teachers who aim to present a balanced picture of physics to their students. For example, physics teachers should always bear in mind the following :

1. The very strong links between science, technology and society. A concern for pollution (particularly about nuclear pollution, after Chernobyl) is perfectly relevant and proper, along with

the issues of renewable energy sources.

2. New technology has transformed many areas of physics and physics teaching. One need only think of audiovisual aids, electronic ways of recording and analysing motion, electronic transducers, and measuring instruments with built-in memories.

3. The introduction of computers provides teachers with so many opportunities - and so many dangers from the improper use of the computer in physics teaching.

4. The new ideas of physics are fascinating; quarks, stellar evolution and attempts to integrate the different kinds of forces are currently of immense importance. But then, so is the level of difficulty of these subjects. Not only will teachers need updating and re-training to understand these ideas, but they will also have to be very careful when attempting to put ideas at this level of difficulty over to students.

5. The history of science is being continually reassessed and re-analysed, to take into account the subjectivity of scientists and their interactions with the worlds of technology, culture, philosophy, and society at the time in which they were or are operating.

6. In several countries, mass instruction has brought with its benefits many new and difficult problems. Simultaneously, and partly as a consequence of mass education, many new centres of educational research have grown up and the number of journals and other publications of possible interest to physics teachers has grown almost exponentially.

7. (This also relates to 6 above) In the last decade or so pupil's thinking, "frameworks", "misconceptions", etc have been recognised and it is to be hoped that the research which has been carried out will soon prove to be of great practical help to classroom teachers.

8. Physics is not a compulsory subject in some countries, in spite of the fact that it is now generally recognised that it is not really possible to make sense of problems in modern technological societies without some sort of orientation in science. In such circumstances there is a need to find ways of presenting the ideas of physics in a not too academic, interesting way, linking the world of school physics with the real world in which the children live, and with the children's perception of that world.

Let me turn to some of the "standard" problems of teaching that face the most fundamental of physics topics: dynamics. It is obvious that with different ages and abilities of students, teachers must adapt their approach and modify their demands. When teaching dynamics, perhaps more than other physics topics, there is a danger that students may be driven away from the delights of physics as a whole if teachers concentrate too narrowly on the more conceptually demanding ideas. When teachers decide to present Newton's laws to students especially at secondary level, they need to give careful consideration to the following topics, and whether and how to put them across. This list is not, of course, exhaustive.

The meaning of inertia; inertial frames of reference; inertial mass and weight of a body; the various definitions of force; operational definition of inertial mass, from the third law (after Mach); the status of the second law, if it is a true law, a definition, or what !; under what circumstances are the third law and the conservation of momentum valid ? Do centrifugal forces exist?

Such problems are fascination for people who are already physicists, but teachers should not place too great an emphasis on them in the beginning, and here it seems appropriate to reproduce some words from a Nuffield Physics manual (p. 95, Teachers' Guide IV)

> These are not philosophical weaknesses in Newton's Laws: they are simply proper parts of the structure of his description of nature. We should not worry pupils or even ourselves about these philosophical matters; and yet we should keep in the back of our mind just enough hint of doubt to prevent us telling pupils that they have proved that Newton's Laws are wholly right. In fact, the Laws are right (subject to some relativistic modification) but they are partly right by definition and partly right because they do describe nature - and the pupils' experiments have illustrated the latter connection.

This booklet is offered in the hope that it will help teachers to bring the meaning of Newton's laws of dynamics to pupils in a way that will interest, intrigue, and excite. In this perspective, it can be pointed out that some of the material presented here lends itself to be used for competitions among students e.g. the best accelerometer that can be made, for corridor type demonstrations e.g. some rotational motions with a turntable and for historical research e.g. about Newton's life. Thus teachers can choose many ways of exploiting this material.

Acknowledgements

I am very indebted to many persons, for stimulating discussions and suggestions about articles, books and so on. Among the many, I would like to single out Brian Davis and M.G. Ebison of the Institute of Physics, Paul Black and John Harris of the Centre for Educational Studies, King's College, London. I wish to thank the many authors who gave permission for the reproduction of their articles in this publication.

Trento (Italy) February 1987 Vittorio Zanetti

Safety

Experiments described in this book have not been tested by ICASE and no guarantee of their safety can therefore be given.

ACKNOWLEDGEMENTS

These notes have been prepared for ICASE by Dr Vittorio Zanetti, the ICASE European Representative with additional help from Dr. Jack Holbrook, the ICASE Executive Secretary. It is their wish that these notes form a valuable resource for teachers from which they may select useful teaching material.

ICASE expresses its very sincere thanks to the above for their efforts and welcomes comments and additional suggestions. ICASE does not impose any copyright on its material for member Associations, but it should be noted that much of this material has been obtained from published sources. A list of such sources is given as an appendix. ICASE has sought permission to reproduce these articles from either the publishers or the authors themselves where copyright rests with them. Where it has not been possible to contact individual teachers ICASE offers its apology for any infringement of copyright, but sincerely hopes such teachers will recognise the value of this resource and its worth in commemorating the 300th anniversary of Newton's Principia. No intentional breach of copyright has been undertaken and ICASE wishes to acknowledge the contribution of the original authors of the articles in making this publication possible.

In many cases it has not been possible to obtain the original photographs and drawings appearing in this book. ICASE wishes to acknowledge the help of Mr. William Pang, University of Hong Kong, in replacing them. Thanks also go to Miss Lilian Chiu and Mrs. Fanny Ho for typing the manuscript. Finally, ICASE thanks Dr. Hubert Brown, Department of Education, University of Hong Kong, for his help in formatting this book, and for his many helpful suggestions.

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UNIT 1 HISTORY AND RESOURCE MATERIALS

I. ISAAC NEWTON - 250TH ANNIVERSARY

P.M. Rattansi

Sir Isaac Newton's life and thought has come under far more concentrated historical scrutiny in the past few decades than ever before. The 250th anniversary of his death (in 1977) provides a convenient opportunity to assess the ways in which this scrutiny has modified the image of Newton we largely inherited from the 18th century Enlightenment, which made him the symbol of a new Age of Reason. Newton's place as the greatest pioneer of modern science is secure. Francis Bacon had called for a new kind of science of nature: Galileo and Descartes sketched the new edifice to be reared on the unshakable foundations of mechanics and mathematics. It was Newton's achievement to realize that dream.

Recent scholarship has only heightened our appreciation of Newton's genius by making us far more conscious of the complex and tangled problems that had to be surmounted before a workable science of dynamics could be established. No easy or inevitable path led from the Copernican cosmology, the "three laws" of Kepler, through the work of Galileo, Descartes, Huygens and others, to the three laws of motion of Newton. Welding the heritage of statics, impetus mechanics and of more recent thinkers and their chaos of definitions into a quantitative measure of force; postulating strange entities like a vis inertiae and gravitational attraction in matter; mastering the mathematical problems of the dynamics of elliptical orbits: all involved challenges which had defeated other thinkers and demanded conceptual and mathematical daring of supreme order.

The significance of the "Year of Miracles" has diminished a little in our historical perspective. Not even Newton could master all the problems in a brief, intense glow of inspiration as the story of the falling apple in the Plague Year suggests. Newton had probably not dispensed with quasi-Cartesian ethereal mechanisms or conceived an universal gravitation even as late as the completion of the first book of the Principia in 1685 (printed in 1687). We are also far more aware of the labours of the 18th century French and Swiss thinkers, which made Newton's achievement the basis for a truly rational mechanics and helped to bridge the gulf which divides the Principia from what is taught in our elementary textbooks as "Newtonian mechanics."

More controversial are the bearings on Newton's scientific work of the other activities we now know deeply to have engaged him in those very years in which he was "in the prime of my age for invention." He plunged into the study of alchemical authors and tested through laboratory operations the recipes he thought he had decoded from their gnomic utterances. He used astronomical dating to improve Biblical chronology. But his overriding concern was to support Protestant reliance on the Bible. He undertook an arduous and minute correlation between sacred prophecy and ancient history to demonstrate the workings of divine providence as prefigured in the Bible.

Some would regard these activities as the aberrations of genius over which it would be kinder to draw a veil. They regret that a founding father of Enlightenment rationalism should now be revealed as fundamentalist in religious beliefs, credulous about alchemical lore and less than godlike when answering critics or asserting priority claims. Others would consider it essential to integrate those aspects into a truer likeness of Newton, a 17th century thinker for whom religious concerns were central in a way they have not been since even for the devout man of science. The concept of universal gravitation became serviceable to science only through the quantitative kinematics and dynamics Newton built on that foundation. But it was a mode of action ruled out by the newly dominant mechanistic conception of nature. It is legitimate to ask whether only within the matrix of such a mind could it re-enter physical thought to establish a truly quantitative science of nature. To select out of the science of the past only that which appears progressive to us is only to increase our sense of bafflement at the juxtaposition of "rational" and "archaic" in past thinkers. Some of the most significant recent advances in understanding have resulted from placing their thought in the context of its own time. Seeming contradictions then often reveal a deeper and unsuspected unity.

Newton himself lent authority to a view of scientific discovery which made it the fruit of inductive generalization from experiment and unprejudiced observation. It shaped the form of the classic paper on light and colours which marked his sensational debut on the stage of science. It was reflected in his angry disavowal of the "feigning" of hypotheses in later years. But the labours of historians have now restored a more just measure of the effort and struggle behind the final form in which they were presented to the world, and of the boldness and imagination which made them possible.

In so doing they have also reinstated a far more inspiring image of great achievement in science as rooted not in a quasi- mechanical process of observation and induction but in the highest resources of thought and imagination of which the human mind is capable, and which found one of its greatest early exemplar in Isaac Newton.

II. A NEWTONIAN MISCELLANY

Brian Gee

In the 250th anniversary year of Sir Isaac Newton's death we might remind ourselves of three earlier tributes to this most remarkable of English scientists:

> Mortals, congratulate yourselves that so great a man has lived for the honour of the human race. (Translation of the inscription on Newton's tombstone in Westminster Abbey)

> Nature and Nature's laws lay hid in night:
> God said, "Let Newton be," and all was light.
> (Alexander Pope's intended epitaph for Newton's tombstone)

> Nearer to gods no mortal may approach.
> (Edmund Halley's "Ode to Newton")

But as for the shy Isaac Newton's view of himself, a little before his death he remarked (Brewster 1855):

> I know not what I may appear to the world, but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a

> prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.

Schoolboy projects

Isaac Newton was born of rather undistinguished farming stock in the Lincolnshire village of Colsterworth. At birth he was so small his mother later remarked that "he might have been put into a quart mug," but from these small and humble beginnings was to develop a child of genius. At the age of nine he was sent to lodge with Clarke, an apothecary in Grantham, whilst he attended the King's School there. In his bedroom he made many ingenious devices, such as the sundial which he later mounted on the south wall of Woolsthorpe Manor. According to J.A. Holden, a recent headmaster of the school,

> He made a water-clock out of a box which he begged from Mrs. Clarke's brother. When finished, it stood four feet high and was of proportionate breadth. The index of the dial-plate was turned by a piece of wood which rose and fell by the action of dropping water. This clock stood in his own bedroom, and he himself kept it supplied with water. It was used as a clock by the Clarke family, and remained in the house long after Newton had left Grantham. (Greenstreet 1927).

His inventiveness also led him to try to make a tread mill to capture "mouse power." A more ambitious project was the building of a windmill which he fixed to the roof of the Clarkes' house. He also designed and made a lantern to light his way to school. Once, his mischievousness led him to attach the lighted lantern to a kite to frighten superstitious locals!

Schoolboy in love?

The strikingly handsome young man of slightly later years did not seem to have lady friends. E.N. da C. Andrade (1950) wrote,

> Women had no attraction for him and it is almost certain that he never had any commerce with sex. The only two women in his life were his mother, to whom he was a dutiful son, and a step-niece who kept house for him for many years.

Certainly, in later years, he begged his friend John Locke not to "embroil" him with women although, in his youth, he did form an attachment for one Miss Storey, a "young and blooming" niece of the Clarkes' where he lodged. Up to his leaving Grantham for Cambridge he preferred her company to his schoolfellows. However, marriage would have caused him to forfeit his fellowship; he did not have the means to support a wife and so consoled himself with his studies.

Newton the trickster

Not without a revolting sense of humour, at the age of 17 Newton wrote down many tricks. One such trick was to turn water into wine (claret):

> Take as much bockwood as you can hold in yor mouth wthout discovery tye it up in a cloth, & put it in yor mouth, then sup some wather & champe ye bockwood 3 or 4 times & doe it out into a glass.

He was also somewhat mischievous at that age. Here is his recipe to make birds drunk:

> Take such meat as they love as wheat, barley, & c. steepe it in lees of wine or in ye juice of hemlock, & sprincle it wher birds use to haunt. Sodden Garlick sprinkled amongst cornes sown.

These and all manner of recipes were first published in Greenstreet (1927).

A question of expenses!

A careful record of spending was kept during his student days (Brewster 1855). It would be fascinating to see such detailed spending of one of today's students! Is the percentage spent on books, compared with what he receives from his mother, more or less what we would expect today?

1665

Received, May 23rd, whereof I gave my tutor 5s.,	5	0	0
Remaining in my hands since last quarter,	3	8	4
In all,	8	8	4

This account of expenses extends only to six and a half pages, and records many loans. The following are among the entries:

Drills, gravers, a hone, a hammer, and a mandril,	0	5	0
A magnet	0	16	0
Compasses,	0	3	6
Glass bubbles,	0	4	0
My Bachelor's account,	0	17	6
At the tavern several other times,	1	0	0
Spent on my cousin Ayscough,	0	12	6
On other acquaintance,	0	10	0
Cloth, 2 yards, and buckles for a vest,	2	0	0
Philosophical Intelligences,	0	9	6
The Hist. of the Royal Society,	0	7	0
Gunter's Book and Sector to Dr. Fox,	0	5	0
Lost at cards twice,	0	15	0
At the tavern twice,	0	3	6
I went into the country, Dec. 4, 1667.			

I returned to Cambridge, Feb. 12, 1667.

Received of my mother,	30	0	0
My journey,	0	7	6
For my degree to the College,	5	10	0
To the proctor,	2	0	0
To three prisms,	3	0	0
Four ounces of putty,	0	1	4
Lent to Dr. Wickins,	1	7	6
Bacon's Miscellanies,	0	1	6
Expenses caused by my degree,	0	15	0
A Bible binding,	0	3	0

Newton's apple

Admiration

When Newton saw an apple fall, he found
In that slight startle from his contemplation -
'Tis said (for I'll not answer above ground
For any sage's creed or calculation) -

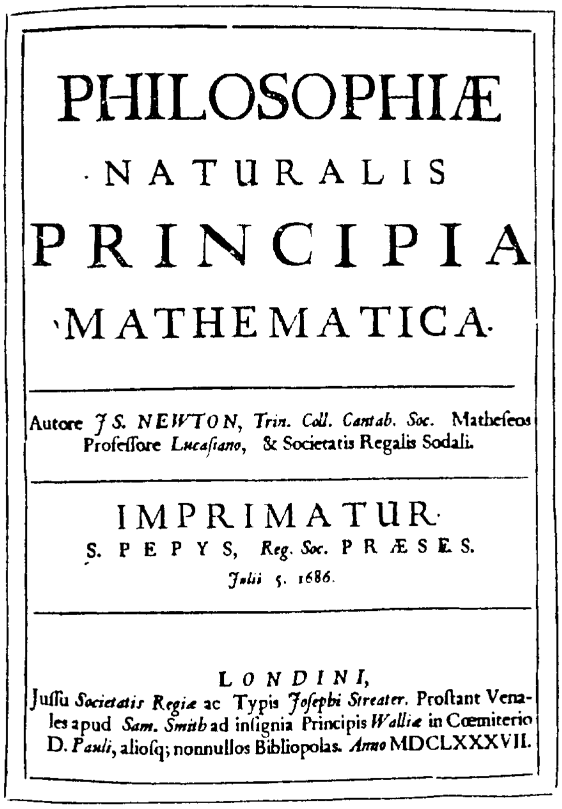
A mode of proving that the earth turn'd round
In a most natural whirl, called "gravitation";
And this is the sole mortal who could grapple,
Since Adam, with a fall, or with an apple.
(Lord Byron 1788 - 1824, poet)

Ridicule

That very lamentable story of the apple which fell before Newton's eyes . . . those who are delighted with the story must have forgotten all the evils an apple has brought on the whole world, including the fall of man and the fall of Troy. The apple is a bad omen for the philosophical sciences.
(Georg Wilhelm Friedrich Hegel 1770 - 1831, philosopher)

Amusing rejection

The history of the apple is absurd. Whether the apple fell or not, how can anyone believe that such a discovery could in that way be accelerated or retarded? Undoubtedly the occurrence was something of this sort. There comes to Newton a stupid, importunate man who asked him how he hit upon his great discovery. When Newton had convinced himself what a noodle he had to deal with, and wanted to get rid of the man, he told him that an apple fell on his nose. This made the matter quite clear to the man and he went away satisfied.
(Karl Friedrich Gauss 1777 - 1855, mathematician)


PHILOSOPHIÆ

NATURALIS

PRINCIPIA

MATHEMATICA.

Autore *JS. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheſeos Profeſſore *Lucaſiano*, & Societatis Regalis Sodali.

IMPRIMATUR.

S. PEPYS, *Reg. Soc.* PRÆSES.

Julii 5. 1686.

LONDINI,

Juſſu *Societatis Regiæ* ac Typis *Joſephi Streater*. Proſtant Venales apud *Sam. Smith* ad inſignia Principis *Walliæ* in Cœmiterio D. *Pauli*, alioſq; nonnullos Bibliopolas. *Anno* MDCLXXXVII.

Newton. Philosophia Naturalis Principia Mathematica 1687.

Fig. 1.1 Title page of **Principia**, 1687 edition

The PRINCIPIA

> Nobody since Newton has been able to use geometrical methods to the same extent for the like purpose, and as we read the **Principia** we feel as when we are in an ancient armoury where the weapons are of gigantic size; and as we look at them we marvel what manner of man he was who could use as a weapon what we can scarcely lift as a burden.
> (William Whewell 1857)

Gilhofer and Ranschburg (Lucerne) recently had a first-edition copy of the **Principia** for sale. The cost of that "half-vellum preserved in a green morocco box" was too high to dare publish but one may imagine a price well into the thousands of pounds!

The book

Taton, in **A General History of Science**, remarks:

> Newton's great work, the **Philosophiae Naturalis Principia Mathematica**, which was to introduce dynamics into cosmology, was the happy issue of his extraordinary powers of abstraction. It begins with definitions and axioms or 'laws' of motion covering the whole of mechanical science.
>
> Newton introduced the notion of 'mass' or 'quantity of matter' into mechanics, thus ridding it of nonmathematical qualities. However, he reserved the right to retain the ether hypothesis

in all cases that could not be reduced to problems of mass. He defined the 'quantity of motion' as the product of mass and velocity, the vis insita, or innate force of matter, as proportional to the mass, and the vis impressa, or impressed force, as an action exerted upon a body in order to change its state, either of rest or of uniform motion in a straight line.

The vis impressa can be produced by impact, by pressure, or by the vis centripeta, by which bodies are drawn or impelled towards a point as to a centre. Unlike the innate and impressed forces, the centripetal force is an action at a distance.

The laws of motion

Newton's laws were not invented to torment schoolchildren! But here they are in their original form:

LEX I. Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus illud a viribus impressis cogitur statum suum mutare.

It is worth remembering that Newton was not the originator of the first law. In the 1630s Descartes had expressed it along these lines: "That each thing as far as in it lies, continues always in the same state; and that which is once moved always continues so to move." Huygens also, in 1673, still 14 years before the Principia, did much better: "If gravity did not exist, nor the atmosphere obstruct the motions of bodies, a body would maintain forever a motion once impressed upon it, with a uniform velocity in a straight line . . . ."

LEX II. Mutationem motus proportionalem esse vi motrici impressae, et fieri secundum lineam rectam qua vis illa imprimitur.

The second law was not the $F = ma$ we accept today. Rather freely translated it would read, "The rate of change of momentum is proportional to the unbalanced force and is in the direction of that force."

LEX III. Actioni contrariam semper et aequalem esse reactionem: sive corporum duorum actiones in se mutuo semper esse aequales et in partes contrarias dirigi.

The third law is quite recognizable today: "To every action there is always opposed a reaction; or the mutual actions of two bodies upon each other are always equal and directed to contrary parts."

The editions

The publication of the original edition created great interest and demand in 18th and 19th century Europe. Some 10 further Latin editions were printed (with many alterations by Newton himself to the second edition (1713), and a new preface added to the final third edition (1726), including two pirated editions in Amsterdam. The first English translation was published in 1729 with a further nine reprints by various editors. Only one French translation existed (1759) and later one German translation (1872). Along with the English editions went five commentaries on the book. The present English version is based on Andrew Motte's translation, revised by Florian Cajori (1962), and is available in Dover paperback.

Table 1 A lifetime's events

Life	Year	Work
Born at Woolsthorpe-by-Colsterworth on Christmas Day.	1642	
	1651	Carved a sundial and fitted to south wall of Woolsthorpe Manor (Now inside Colsterworth church).
Went to King's School (Grantham).	1654	
	1655-6	Engaged in various model-making activities.
Reputed attachment for one Miss Storey.	1656	
Step-father died. Returned home to become a farmer. Quickly returned to school on advice of the headmaster.	1657	
Entered Trinity College, Cambridge. Bought some prisms at Stourbridge fair.	1661	
	1663-4	Studied Descartes, Oughtred and Wallis.
Obtained B.A. degree and elected Scholar.	1664	Studied the 1664 comet. Gave theory of halos.
Returned home on account of the Great Plague. Purchased many books and tools to spend his time fruitfully.	1665	Found the method for approximating an infinite series. (Hooke's **Micrographia** published). Began to work on fluxions (calculus). Found method of tangents.
	1666	Theory of colours. Early work on gravitation.

Returned to Cambridge. Elected Fellow.	1667	Ground and polished lenses and prisms.
Obtained M.A. degree.	1668	Made a refractor. Saw Jupiter's satelites and the horns of Venus.
Issac Barrow retired from the Lucasian Chair of Mathematics in favour of Newton.	1669	Gave lectures in optics and published them.
	1670-1	Researched in optics; devised a reflecting telescope and sextant. Discovered the compound nature of white light. Studied diffraction and the colour of thin films.
	1671	Demonstrated a larger telescope to Charles II and presented it to the Royal Society.
Elected Fellow of the Royal Society.	1672	Reputedly began work on gravitation in silence after hearing of Picard's new measures of the Earth.
	1672	Account of "The new Catadioptrical telescope."
Threatened to resign from Royal Society because of controversy over his optical theory.	1672	Communicated "New theory of light and Colour."
Made friends with Locke.	1680s	
	1684	Halley sought help from Newton on the inverse-square law problem set by Christoper Wren.
	1685	First mathematical proof of the inverse square law in De Motu
	1685-6	Preparation of his magnum opus.

Defended successfully the University against a high-handed action of James II concerning Catholicism.	1687	**Principia** published.
Elected to Parliament.	1689	
	1690	Huygens' **Traite de la Lumiere** published.
Nervous breakdown (reputed)	1692	
	1692	Method of fluxions first published in Wallis's **Opera Omnia**
Made Warden of the Mint.	1694	
	1696	Responded anonymously and successfully to a mathematical puzzle set by a Swiss mathematician when 75 years old!
Made Master of the Mint.	1697	
Elected President of the Royal Society.	1703	Robert Hooke died.
	1704	**Opticks** published (contained an independent account of his calculus).
Knighted by Queen Anne.	1705	
	1706	**Optice** (first Latin edition).
	1713	**Principia** (2nd ed. aided by Cotes).
	1717	**Opticks** (2nd ed.)
	1721	**Opticks** (3rd ed.)
	1726	**Principia** (3rd ed.)
Died Kensington (20 March). Buried Westminster Abbey.	1727	
	1730	**Opticks** (4th ed.) revised by Newton.

The OPTICKS

(.................................)

The religious man

> Mr. Newton is a very valuable man, not only for his wonderful skill in mathematics, but in divinity too, and his great knowledge of the Scriptures, wherein I know few his equals.
> (John Locke, his friend and philosopher)

Newton was a Unitarian but never took Holy Orders and therefore could never have been made Master of Trinity College. Nevertheless, he had nearly one and a half million words published on religion! His work on Daniel and the Apocalypse was a work of some ingenuity. He also made a curious remark in the last query of the **Opticks** (2nd edn) when he wrote, "All these things considered, it seems probable to me, that God in the beginning formed Matter in solid, massy, hard, impenetrable, moveable Particles . . . ."

Even in his monumental work, the **Principia**, he records, in the preface of the 1713 edition, that we may

> Nearly behold the beauties of nature, and entertain ourselves with their delightful contemplation; and, which is the best and most valuable part of philosophy, be thence excited the more profoundly to reverence and adore the Maker and Lord of all. He must be blind who, from the most wise and beautiful contrivances of things, cannot see the infinite wisdom and goodness of their almighty Creator; and he must be mad or senseless, who refuses to acknowledge them.

Places to visit:

Woolsthorpe Manor: Perhaps you are the sort of person who takes to pilgrimaging when on holiday? Newton's birthplace is now owned by the National Trust and is open on the (nearly) corpuscular (!) days of Mondays, Wednesdays and Saturdays. There is not much to see but it is just off the Great North Road (A1) - if you are journeying that way - at Colsterworth, midway between Grantham and Stamford. In Grantham there is a museum which contains some of Newton's relics and Newton's school, the 15th century King's School.

Cambridge: Newton's rooms at Trinity College are on the first floor, just to the north of the Great Gate. There is also Roubiliac's fine statue of Newton in Trinity College Chapel. The cloisters under the Wren Library at Trinity were used by Newton in an attempt to determine the exact speed of sound by the method of echoes. The great south window of Trinity College library was made in 1775 and shows Sir Isaac Newton being presented to George III by Cantarigia with Fame, Britannia and Sir Francis Bacon. Finally, at the Fitzwilliam Museum there is a rather fine painting by Pittoni called **Allegorical Monument to Sir Isaac Newton.**

Literary circles

> Newton with his prism and silent face
> The marble index of a mind for ever
> Voyaging through strange seas of thought alone.
> (Wordsworth's reaction on seeing Newton's statue at Trinity College)

Newton's discoveries and Laplace's mechanical interpretation of them led many poets to shun what they believed was Newtonian philosophy. Keats felt that Newton had destroyed the beauty of nature and, along with Wordsworth and Lamb, at a dinner party in 1817, he toasted "Newton's health, and confusion to mathematics." On the other hand, Blake, Coleridge, Byron, Shelley and Wordsworth admired the marvels of science and this is reflected in their works. A fascinating account of Newton's influence on literature and aesthetics is to be found in Kline (1954).

The last word

We started this miscellany by referring to Pope's epigram on Newton. Sir John Collings Squire (1884-1958) replied to that by adding:

> It did not last: the Devil howling Ho!
> Let Einstein be! restored the status quo.

But I wonder who will have the last word in this new "charmed" world of quarks and black holes. There is an air of mysticism about Nigel Calder's BBC TV epic **The Key to the Universe** (1977). Does this view finalize our study of the physical world or should we perhaps turn to Fritjof Capra's **The Tao of Physics** (1975) and his parallels between physics and Eastern mysticism?

In this quarter-millennium of celebrating the great Newton, let him have the last word (and warning?):

> Physics, beware of metaphysics.

REFERENCES

Brewster D. 1855 **Memoirs of Isaac Newton** (London: Constable) vol.2 ch.27

Greenstreet W.J. .1927 **Isaac Newton 1642-1727** (London: Bell)

Kline M. 1954 **Mathematics in Western Culture** (London: George Allen and Unwin)

III. RESOURCES FOR NEWTONIAN STUDIES

Brian Gee

Over the past decade there has been a slight but definite introduction of science history into courses of all kinds. There is an ever growing field of Newtonian studies in higher education, but there is also room for young scientists in sixth forms to have their eyes opened to the origins of modern science. Whether you wish to simply personalize Newton the man or follow the development of an idea such as gravitation or examine how Newtonian thought influenced Western culture then this article may be a useful starting point. The intention has not been to provide a definitive bibliography such as may be obtained from the ISIS cumulative index but simply to offer an array of sources which may be of value to those faced with course construction or stocking library shelves. The following lists show 1976-7 prices, OP indicating books out of print in 1976.

Bibliographies

Andrade E.N. da C. 1953 'A Newtonian collection' **Endeavour** 12 pp. 68-75.

Gray G.J. 1967 **Bibliography of the Works of Sir Isaac Newton** London: Dawsons.

Zeitlinger H. 1927 'A New bibliography' in Greenstreet W.J. (ed) **Isaac Newton 1642-1727** London: Bell pp. 148-70.

General books

The following is a list of books suitable for school libraries.

Aicken F. 1970 **Newton - Architect of the Scientific Society** London: English University Press, price 25p.

Andrade E.N. da C. 1958 **Sir Isaac Newton: His Life and Work** New York: Doubleday, price $1.95.

Bronowski J. 1969 **The Common Sense of Science** (ch. 3 'Isaac Newton's model') London: Heinemann, price 90p.

Cohen I.B. 1961 **Birth of a New Physics** (On the astronomical background of Newtonian physics) London: Heinemann, price 55p.

Crowther J.G. 1960 **Founders of British Science** Cresset OP.

Gordon S. 1969 **Pageant of Scientists** Oxford: Blackwell, price 80p.

Hoskin M. 1971 **The Mind of the Scientist** (Imaginary interviews with scientists including Newton) London: B.B.C. Publications, price £1.50.

Hutchings D. (ed) 1969 **Late Seventeenth Century Scientists** Oxford: Pergamon, price £1.80.

Leech G. (ed) **Newton and Gravitation** (A collection of facsimiles for exhibition) London: J. Cape Jackdaw Publications OP.

Project Physics 1976 **Motion in the Heavens** (unit 2), **The Triumph of Mechanics** (unit 3) (Suitable account and laboratory exercises for sixth-formers in the **Text and Handbook** version) Eastbourne: Holt-Saunders, price £3.50 each.

Ronan C. 1976 **Isaac Newton** Shire price 60p.

Sootin H. 1955 **Isaac Newton** (A fictional biography for young people) Messner OP.

Steele D. (ed) 1970 **The History of Scientific Ideas** (ch. 1.6 sets out a background plan for Newtonian studies at sixth-form level) London: Hutchinson OP.

Other biographies

Andrade E.N. da C. 1950 **Isaac Newton** Parrish OP.

Crowther J.G. 1960 **Founders of British Science** Crescent Press OP.

Keynes J.M. 1947 **Newton the Man** London: Royal Society OP reprinted in Boorse H.A. and Motz L. (eds) 1966 **The World of the Atom** New York: Basic OP.

Lodge O. 1960 **Pioneers of Science** (A welcome reprint containing three of Sir Oliver Lodge's famous lectures on Newton) New York: Dover, price £1.95.

Manuel F.E. 1968 **A Portrait of Isaac Newton** Harvard University Press OP.

More L.T. 1962 **Isaac Newton: A Biography** Smith, price $6.50 (available in Dover).

Stukeley W. 1936 **Memoirs of Sir Isaac Newton's Life** London: Taylor and Francis OP.

Commentaries

The following list gives a selection of commentaries.

Cohen I.B. (ed) 1971 **Introduction to Newton's Principia** Cambridge: Cambridge University Press, price £21.

Hall A.R. 1976 **From Galileo to Newton** (Necessary background reading) London: Fontana-Collins, price 60p.

Hall M.B. 1970 **Nature and Nature's Laws** (A documentary about the Renaissance) London: Harper, price £2.

Herival J. 1966 **The Background to Newton's Principia** Oxford: Oxford University Press, price £5.40.

Kline M. 1954 **Mathematics in Western Culture** London: George, Allen and Unwin OP, reprinted Harmondsworth: Penguin, price £1.

Koyre A. 1961 **Newtonian Studies** University of Chicago, price £1.65.

Manuel F.E. 1974 **Religion of Isaac Newton** Oxford: Oxford University Press, price £3.50.

Rattansi P.M. 1974 **Isaac Newton and Gravity** Priory, price £3.25.

Wolff P. 1965 **Breakthroughs in Physics** (Contains a section on Newton's breakthrough with the mathematical principles of physics) New English Library OP.

Memorial editions

Brewster D. 1860 **Memoirs of the Life, Writings and Discoveries of Sir Isaac Newton** (2 vols) (A base book dedicated to Prince Albert, from which many of today's writings on Newton stem.) London: Constable.

Greenstreet W.J. 1927 **Isaac Newton 1642-1727** London: Bell. A memorial volume written for the Mathematical Association. Contains short scholarly papers on Newton's study of: (a) interpolation (by D.C. Fraser), (b) optics (E.T. Whittaker), (c) the solid of least resistance (by A.R. Forsyth), (d) the theory of tides (by J. Proudman), (e) the geometry of conics (by J.J. Milne), (f) the art of discovery (by J.M. Child), (g) influence on method in the physical sciences (by A.E. Heath) as well as other aspects of Newton's life in 17th century England.

Palter R. (ed) 1970 **The Annus Mirabilis of Sir Isaac Newton** (A collection of papers on Newton's life presented at a conference) Cambridge, Mass: MIT Press.

Royal Society 1946 'Tercentenary celebrations 15-19 July 1946' **Notes Rec. R. Soc. Lond.** 4 152-7.

Extracts

The following works contain extracts from Newton's papers in the **Philosophical Transactions of the Royal Society**, his **Opticks** and the **Principia**, and are generally available through libraries, or may be purchased in the Dover reprint series. Scholastic studies by D.T. Whiteside and M.A. Hoskin, J.F. Scott, A.R. Hall and M.B. Hall and A.R. Hall and A. Tiling are thought to be out of the realms of undergraduate study and are not mentioned here.

Cohen I.B. (ed) 1958 **Isaac Newton's Papers and Letters** Cambridge University Press OP.

Hurd D.L. and Kipling 1958 **The Origins and Growth of Physical Science** Harmondsworth: Penguin OP.

Magie W.F. (ed) 1964 **A Source Book in Physics** Harvard University Press, price £9.90.

McKenzie A.E.E. 1960 **The Major Achievements of Science** vol. 2 Cambridge University Press OP.

Moulton F.R. and Schiffres J.J. 1963 **The Autobiography of Science** London: Murray OP.

Thayer H.S. (ed) 1976 **Newton's Philosophy of Nature** Hafner, price £1.50.

Articles and essays

The following list gives a selection of recent papers concerning physics only. The symbol "*" indicates articles suitable at sixth-form level, while "+" indicates essays for advanced study.

Andrade E.N. da C. 1943 'Newton and the apple' **Nature** 151 84. Based on Voltaire's account.

Andrade E.N. da C. 1942 'Newton and science of his age' **Nature** 150 700-6. Address delivered to Royal Society.

*Cantor G. 1977 'Newton's telescope' **Phys. Educ.** This issue.

*Cantor G. 'The experimentum crucis' **Phys. Educ.** To be published.

*Cohen I.B. 1955 'Isaac Newton' **Sci. Am.** 193 73-80.

Crombie A.C. 1957 'Newton's conception of scientific method' **Bull. Inst. Phys.** 8 350-62.

*Gee B. 1977 'Gravitation as Newton first saw it' **Phys. Educ.** September. A reconstruction of the apple story with figures provided for a student exercise.

*Gee B. 1977 'A Newton miscellany' **Phys.Educ.** September. Some snippets for amusement and information.

*Gee B. 1977 'Newton: have we got his dates right?' **New Scientist** 73 1043 (17 March) 644. Difficulties of changing from Julian to Gregorian time.

+Guerlac H. 1967 'Newton's optical aether' **Notes Rec. Rd. Soc. Lond.** 22 45-57.

+Hall A.R. 1957 'Newton on the calculation of central forces' **Ann. Sci.** 13 62-71.

+Hall A.R. 1959 'Newton's electric spirit: four oddities' **Isis** 50 473-6.

+Hall A.R. 1959 'Newton's mechanical principles' **J. Hist. Ideas** 20 167-78.

+Hall A.R. 1960 'Newton's theory of matter' **Isis** 51 131-44.

*Hawes J.L. 1977 'Newton, particles and concepts of force' **Phys. Educ.** September. Shows Newton had some remarkable foresight on the place of nature's forces.

+Hawes J.L. 1968 'Newton's aether hypothesis and the explanation of gravitational attraction' **Notes Rec. R. Soc.** 23 200-12.

+Hawes J.L. 1968 'Newton and "The Electrical Attraction Unexcited"' **Ann. Sci.** 24 121-30.

+Hawes J.L. 1971 'Newton's two electricities' **Ann. Sci.** 27 95-103.

*Heiskanen W.A. 1966 'A view of Sir Isaac Newton's philosophy' **Phys. Teach.** January.

Herival J.W. 1961 'Newton's test of the inverse square law against the moon's motion' **Arch. Int. Hist. Sci.** 14 97.

+Home R.W. 1968 'The third law in Newton's mechanics' **Brit. J. Hist. Sci.** 4 39-51. The empirical background to Newton's statement on this law.

+Iltis C. 1973 'The Leibnizian-Newtonian debates' **Brit. J. Hist. Sci.** 6 343-77. How the mechanical arguments of each related to their metaphysical systems.

*Joel B.J. 1977 'In gratitude--250 years of light' **Sci. Teach.** 44 28-9.

Layton D. 1957 'Newton's effect on English thought' **Hist. Today** 7 388-95.

+McGuire J.E. and Rattansi P.M. 1966 'Newton and the "Pipes of Pan"' **Notes Rec. R. Soc.** 21 108-43.

*Maxwell H.N. 1970 'Newton's period in history' **Phys. Teach.** 8 329-32. An outline of events in Newton's lifetime.

Miller J.E. 1951 'How Newton discovered the law of gravitation' **Am.Sci.** 39 1 reprinted in Weber R.L. (ed) 1973 **A Random Walk in Science** London and Bristol: Institute of Physics. A spoof article. Beware!

Sabra A.I. 1963 'Newton and the "bigness of vibrations"' **Isis** 54 267-8.

*Watson E.C. 1954 'Caricatures of Sir Isaac Newton by two famous artists' **Am.J.Phys.** 22 247-9.

Westfall R.S. 1962 'The development of Newton's theory of colour' **Isis** 53 339-58.

Whiteside D.T. 1970 'Before the **Principia**' **J.Hist.Astron.** 1 5-19. On the maturing of Newton's thoughts on dynamical astronomy 1664-1684.

+Whiteside D.T. 1964 'Newton's early thoughts on planetary motion: a fresh look' **Brit.J.Hist.Sci.** 2 117-37.

Whiteside D.T. 1962 'The expanding world of Newtonian research' **Hist. Sci.** 1 16-29, 86-90, 96-100.

*Whiteside H. 1964 'Newton's derivation of the velocity of sound' **Am.J.Phys.** 32 384.

Yates F. 1977 'Did Newton connect his maths and alchemy?' **Times Higher Education Supplement** 18 March p.13. A discussion of the impact of Hermetic philosophy.

Teaching aids

Films

The Majestic Clockwork 1972 BBC-Time Life. Part 7 of Jacob Bronowski's **Ascent of Man.** 50 min, col, hire charge £12, dist. BBC Enterprises, 25 The Burroughs, Hendon, London NW4 4IB.

The Construction of the Heavens Open University. Deals with the problem posed for cosmographers after the introduction of Newton's gravitational law. Hire charge £6.80 (b and w), £8.50 (col), dist. Guild Sound and Vision, Woodston House, Oundle Road, Peterborough PE2 9PZ.

God said, "Let Newton be" Open University. Deals with the behaviour of planets in the solar system, the concept of celestial harmony, the notion of God as mathematician and finally, the formation of mathematical laws based on Kepler and Newton. Hire charge and dist. as **The Construction of the Heavens.**

Isaac Newton 1960 Coronet USA. Deals simply with how Newton arrived at the binomial theorem, integral calculus, the theory of light and the laws of gravitation. 14 min, b and w, hire charge £3.46 (inc. VAT and postage), dist. Gateway. Available from the National Audio-Visual Aids Library (NAVAL), Paxton Place, Gipsy Road, London SE27 9SR.

The Force of Gravity 1962 Planet Earth. Demonstrates the nature of gravity and how Newton and others made attempts to understand it. Covers the effect of the moon on tides and the use of artificial satellites in current research. Also, a brief look at Einstein's concept of gravity. 27 min, col, hire charge £6.26 (inc. VAT and postage), dist. McGraw-Hill. Available from NAVAL.

Newton: The Mind that found the Future 1971 The Learning Corporation of America. Explains Newton's work in relation to his own lifetime and shows contemporary applications of his theories. Edmund Halley moves freely between his and the present age to reveal Newton, the man who was irascible with his rivals. 21 min, hire charge £5.89 (inc. VAT and postage), dist. Rank. Available from NAVAL.

Other materials

Filmstrip. Contains portraits, drawings and reproductions of contemporary prints to illustrate the career of Isaac Newton. Particular reference to his theories of light and colour. 21 frames, b and w with notes, not for hire, dist. NAVAL.

Film loops. Various loops exist to demonstrate Newton's laws. Consult NAVAL catalogue.

Science Museum. Holds a replica of Newton's telescope (the original being with the Royal Society). Photographs and slides are available thus: **Replica of Newton's Telescope** (neg no. 6819), **An Engraving of Newton's by J. Smith** c1712 (neg no. 1080), **A Line Engraving by J. Vanderbank** (neg no. 162/60). Reproduction charges: 40p + 3p (VAT) for 8 1/2 inch x 6 1/2 inch photographs, 35p + 3p (VAT) for 3 1/4 inch x 3 1/4 inch or 2 inch x 2 inch slides. Postage: 14p (inland) or 48p (overseas).

Dist. The Photographic and Lantern Service, The Science Museum, South Kensington, London SW7 2DD.

Student experiments. Some interesting historical plotting experiments exist in the Project Physics materials (Eastbourne: Holt-Saunders): (a) "Stepwise approximation to an orbit" enables a student to plot a comet's orbit. The experience dramatizes the directional nature of a central force due to an inverse-square law (unit 2 **Motion in the Heavens**). (b) "A crowning triumph for Newtonian theory" is a graphical exercise based on the prediction of Neptune's orbit (supplement B **Discoveries in Physics**). The Chelsea Science Simulation Project have published an interesting simulation: (c) "Newton" allows students to extend Newton's work on projectiles. The aim is to get a body into orbit (unit on **Satellite Orbits** by John Harris and published by Edward Arnold 1975).

Tape recording. **The Enigmatic Force** UNESCO Radio. A special anniversary programme to celebrate Newton's work on gravitation. Contains some biographical material. Suitable for fifth or sixth forms. Copy charge (1977) £2.50 (inc. postage). Specify cassette or reel to reel. Dist. Brian Gee, College of St. Mark and St. John, Plymouth PL6 8BH.

UNIT 2 RESISTING CHANGES

I. TRICKS THAT ILLUSTRATE INERTIA

Nuffield O-level Year 3

You may see or try some of the experiments sketched in Figures 2.1 and 2.2.

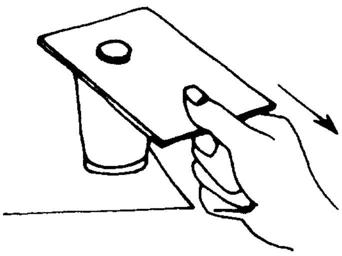


Fig. 2.1

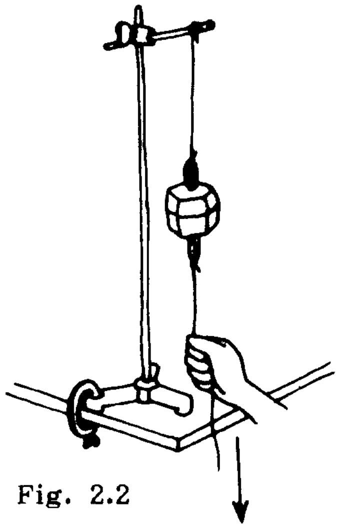


Fig. 2.2

II. a) CHECKER SNAPPING

Project Physics

Stack several checkers. Put another checker on the table and snap it into the stack. On the basis of Newton's first law, can you explain what happened?

b) BEAKER AND HAMMER

Project Physics

Place a glass beaker half full of water on top of a pile of three wooden blocks. Three quick back-and-forth swipes (NOT FOUR!) of a hammer on the blocks leave the beaker sitting on the table.

III.

H.F. Meiners (Editor)

The inertia of an object is often demonstrated by "snapping" a 3 x 12 cm card out from under the base of a tall object without significant movement of the object. An interesting modification of this experiment is to balance the end of the handle of an ordinary claw hammer on a shipping tag lying on the edge of the table and then jerk the shipping tag out by means of a loop of strong string attached to the tag. If the loop of string is about 20 cm long, the hand of the lecturer can attain considerable speed before the slack in the loop is taken up, giving a quick jerk to the card.

IV. INERTIA DEMONSTRATION

Alfred M. Eich, Jr.

The usual apparatus for demonstrating Newton's Law of Inertia consists of a dimple-topped stand with a spring strip and a steel ball (Welch Scientific Co. No. 0543). A calling card is placed on the stand, the ball is placed on the card directly over the dimple; the spring fires the card out from under the ball which drops into the dimple. A water glass, 8 cm x 13 cm card, and a dime also work well (see Dull, Metcalfe, and Williams, Modern Physics, p.89, 1964 edition). The demonstration has much more value if friction is introduced and a light-weight ball is used. If the calling card is replaced with a piece of sandpaper (sandy side toward the ball), the steel ball will now follow the sandpaper and will not drop into the dimple. If a cork ball replaces the steel ball, it will follow the card and not drop into the dimple. Excellent discussions involving the concept of "unbalanced force" usually follow these demonstrations. Of course, a completely set table with a linen tablecloth may be used if one really has confidence in physics - or himself!

V. A 'MAGIC' MOTIVATOR IN THE SCIENCE OF INERTIA

Alan Ward

The look of astonishment on Donald Duck's face at the instant he realizes that he has run over the edge of the cliff-- and is now poised in mid-air--is an excellent mental picture of an inert body at the moment its support is removed. Donald's motion over the cliff is analogous with the pulling away of a tablecloth beneath a gleaming array of cups, saucers, jugs and plates. If the trick is smartly done, the inertia of the crockery is virtually unaffected by friction with the cloth. Therefore the crocks settle with a rattle on to the bare table. Meanwhile, back in space, Donald Duck hurtles into a yawning chasm.

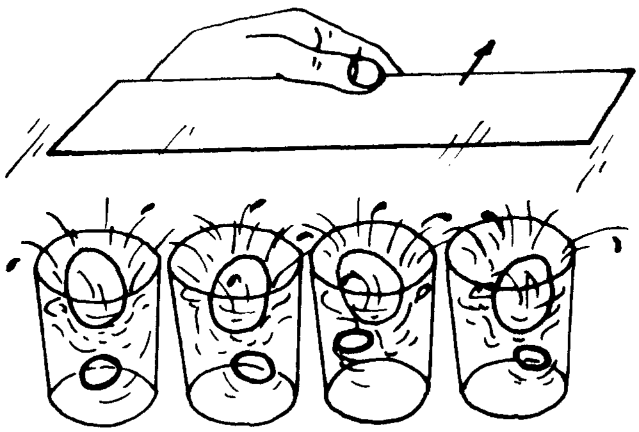


Fig. 2.3

A famous juggling trick with eggs excites the juvenile imagination more boldly than references to Johnny's sensations, when father's car is started with a jerk. The eggs are standing up on end over small curtain rings resting along a strip of stout cardboard. Directly beneath each of the four eggs used for the demonstration is a glass container half-filled with water. Grip a long edge of the card. (The atmosphere is tense and ripe for humour!) Then pull the card suddenly straight outward. Momentarily the eggs stay in mid-air--before plunging down and splashing neatly into their respective glasses. Voila!

VI. THE TABLECLOTH PULL

Joseph Perez

Pulling a table cloth from under a full setting of dishes is one of the most lively and dramatic ways to illustrate Newton's first law. With a little practice it is easy to perform.

It is best to start out by pulling the cloth from under a single object. After you get the feel for the quick downward pull needed, a complete setting can be tried. The table cloth should be cotton with a texture similar to a bed sheet. The cloth should have no seams or hems. The table top should be smooth without any edge trim protruding above the surface. The dishes should not have jagged edges on the bottom. Before pulling the cloth all slack and wrinkles should be taken up.

If the objects get pulled off the table it is probably because the cloth is not being pulled quickly enough down over the table's edge.

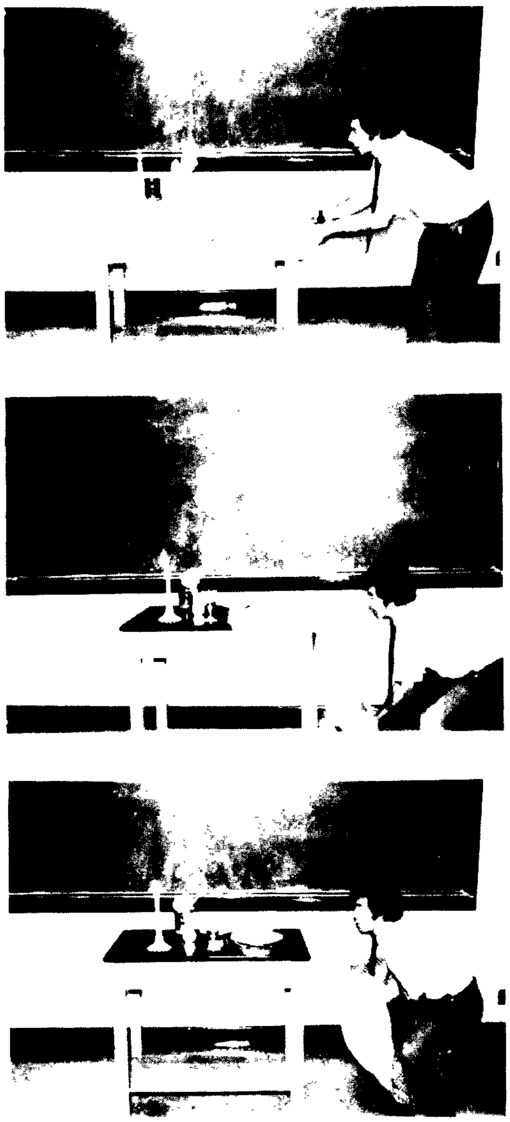


Fig. 2.4 Everything remains in place after the demonstration

VII. H.F. Meiners (Editor)

A 20 kg mass is mounted on a plank resting on rollers. A force is applied through a thread to the plank, and the weight slowly accelerates. Next, a 2 metre length of clothesline with a hammer tied to one end is attached to the weight. When the hammer is whipped forward at high speed, the rope breaks, and the heavy weight is scarcely disturbed.

VIII. H.F. Meiners (Editor)

A small cart a is free to roll on a larger cart b which is moving at constant velocity toward a rigidly mounted compression spring (Figure 2.5). As soon as the large cart makes contact with the spring, the smaller one moves forward, and continues moving forward as long as no force is applied to it. This effect may also be shown in the following manner: A U-tube half full of red water c is mounted on the large cart and the demonstration is repeated. As long as the velocity of the cart is constant the liquid will be the same height in both sides. As soon as the cart contacts the spring, the liquid in the tube closer to the spring will rise, while the liquid in the other tube falls.

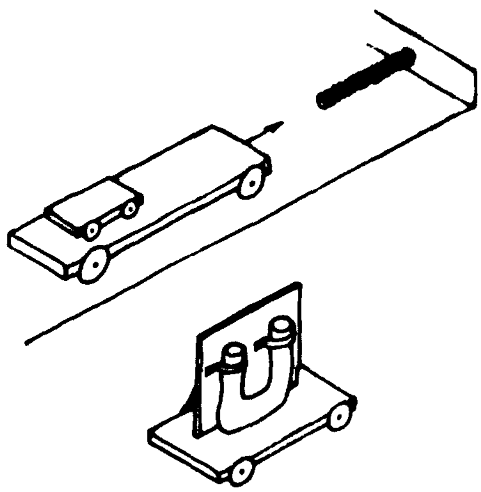
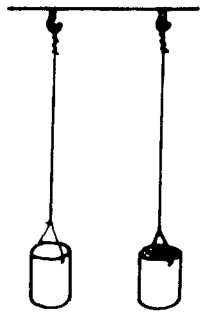


Fig. 2.5

IX. FEELING INERTIA Nuffield O-level Year 3

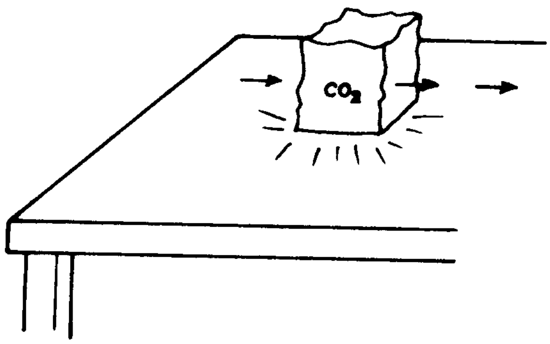


Try the experiment sketched. One tin can is full of sand, the other empty. Try pushing each to start it moving. Try stopping each when it is moving.

Why are safety belts worn in cars? What happens to passengers on the back seat with no safety belt, when the car suddenly stops? What happens when it suddenly starts? When it goes round a sharp corner?

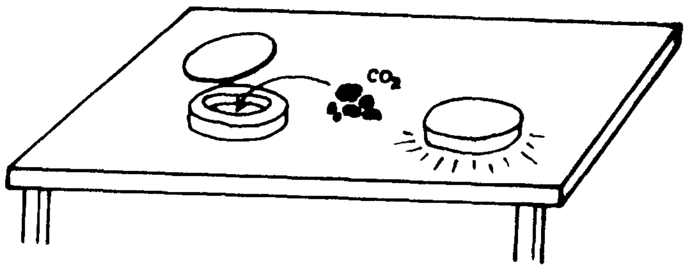
X. a) FRICTIONLESS MOTION: HOVERCRAFT Nuffield O-level Year 3

See one or more of the demonstrations sketched. They show an object moving with practically no friction on a level table.



b) THE COASTING ICEBERG Nuffield O-level Year 3

Solid carbon dioxide ('dry ice') is very cold. It turns into gas when it touches the warm glass, and the gas can support an object, as air supports a hovercraft.

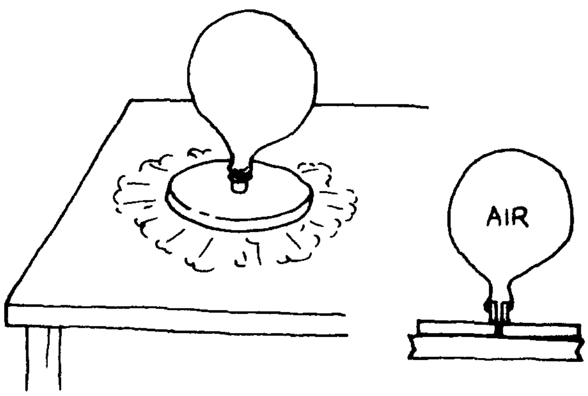


c) RING HOVERCRAFT Nuffield O-level Year 3

A little solid carbon dioxide turns to gas and that supports the ring. (Or a tiny air pump driven by batteries can maintain a hovercraft 'puck' for a longer time.)

XI. HOME-MADE HOVERCRAFT Nuffield O-level Year 3

A balloon squirts air out through a hole in a small wooden disk, and that makes a hovercraft.



XII.

INERTIA DEMONSTRATION Paul Hewitt

There are many ways to impart the idea of inertia or mass to a class. Perhaps the simplest is to hand a student some small objects, such as a pair of metal spheres, and ask him to judge which is heavier. Chances are that he will shake them back and forth or move them about in order to make his judgment. You can then point out that in so doing he is actually making a comparison of inertia rather than weight, and then go into a discussion of the proportionality of mass and weight.

A useful demonstration is shown in Figure 2.6 It is the idea of one of my students, George Haddock, who also constructed it by simply suspending two large cylindrical blocks of like appearance from cables so that their displacements could be compared after being struck with a sledge hammer. The upper block consists of a 3-kg wooden disk and the lower block is a 50-kg cylinder of iron. It is easily seen that when a striking force is impressed on each block the more massive block offers a greater resistance to a change in its state of motion. By making both blocks the same size, the distinction between mass and volume is more easily made. Students are invited to push the blocks with their hands before leaving the room.

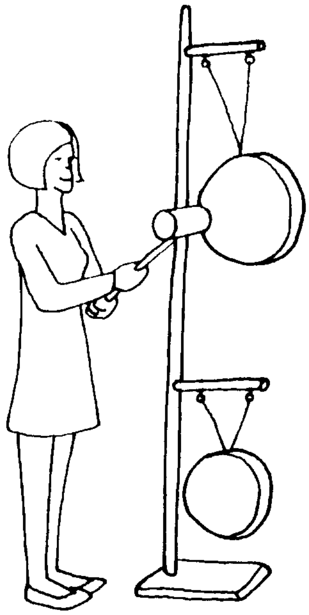


Fig. 2.6 An inertia demonstration apparatus.

XIII. H.F. Meiners (Editor)

Several simple demonstrations of inertia are possible, among them the following: An 8 kg lead or steel brick(1,2) is placed in the hand and struck a vigorous blow with a hammer; no visible momentum is transferred to the hand. A 20 kg brick(1) can be placed on the stomach or chest and struck by an assistant to duplicate this effect. Similarly, a 20 to 30 kg wooden block(3) can be placed upon a person's head, and nails driven into the block. The large forces from the hammer are of such short duration that the block acquires no appreciable velocity.

1. G.D. Freier, University of Minnesota.
2. E.B. Nelson and W.E. Nickel, State University of Iowa.
3. R.M. Sutton, California Institute of Technology.

XIV. EXPERIMENTS WITH SIMPLE EQUIPMENT Andrew Ahlgren

(........)

An Experience with Inertial and Gravitational Mass

The equivalence of inertial and gravitational mass is a fruitful puzzle in physics, and one well worth pursuing in a high school course. A great deal of student response is generated by those "gedanken" experiments where behavior in a uniform gravitational field is compared with behavior in a uniformly accelerated system. It is often difficult, however, to convince the students that the equivalence should be at all surprising. The PSSC exercise is useful in this respect, but the ideas are somewhat lost in the fairly complex data. We have just recently tried a simple game that affords students a vivid experience in the distinction between inertial and gravitational mass.

Bodies of various masses, cord, and a "frictionless" cart are laid out on the demonstration table, and a volunteer is blindfolded. One of the bodies is attached to a cord and given to the subject. He has been instructed that he must not move the body about, but just support it and sense the force with which gravity is acting upon it. His other hand is then put in contact with the cart. He has been instructed not to lift the cart, but only to move it back and forth so as to sense the force required to accelerate it. Mass is added to the cart until the subject judges that the mass he is supporting and the mass of the cart are equal.

Excitement in the class mounts high as the mass of the cart becomes from three to six times greater than the suspended mass and the subject still calls for more. (Skeptical students may have to be satisfied by using the same hand for both tasks or by arranging a pulley so that the weight can be supported horizontally.) It is not unusual for the subjects to make the point themselves: "There's no way to compare them!"

The force they feel will depend, of course, on the acceleration given the cart. The group can usually supply the suggestion that a particular acceleration be used consistently; if they can be led to suggest that the acceleration should be g, then those "gedanken" experiments will come tumbling in of their own accord. Depending on the sophistication of the students, it might be wise to lay a foundation by first having the subject similarly judge the equality of masses by support and by cart moving separately. Variations to suit a particular class readily suggest themselves.

XV. H.F. Meiners (Editor)

A low-friction puck "inertial balance" may be constructed very easily by fastening soft springs to screw eyes imbedded in a plastic puck rolling on 0.5 mm diam plastic beads of Dylite.(1) The springs are anchored as shown in Figure 2.7 and masses of 100, 200, 300, 400, and 500 g are placed on the puck; for each mass, five oscillations of the puck are timed on a stopwatch and a plot of time vs mass may be constructed. The best-fit curve through these points is the inertial mass calibration curve for the oscillator. Two objects of different unknown masses are then placed, one at a time, on the puck and five oscillations are timed for each. Their masses may be read off the calibration curve and then obtained with a spring balance. The conclusion reached will be that the objects' weights are in the same ratio as their masses.

(1) Dylite expandable polystyrene beads are available from the Sinclair-Koppers Company, Pittsburgh, Pennsylvania. These beads are also useful when introducing concepts of viscous fluid flow. Unexpanded, the beads will reach terminal velocity in water in about 2 cm. After being boiled in water, the expanded beads will reach terminal velocity in air in about 45 cm.

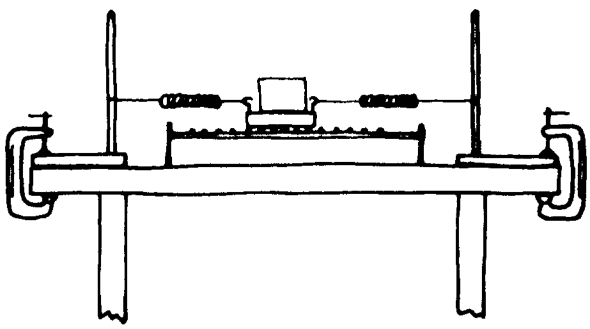


Fig. 2.7

XVI. A DIRECT-READING INERTIAL BALANCE

Luciana Bruzzi

The direct-reading inertial balance described in this note consists of two oscillators, weakly coupled. One supports the mass holder together with the coupling to the second, which is a flat metal spring. When the first is put into oscillation, its frequency will depend on: (i) the mass of the holder and the mass it contains; and (ii) the position of the centre of mass of the holder and contents with respect to the centre of oscillation.

The second oscillator, in general, makes small irregular vibrations. However, if the position of the mass holder is adjusted carefully until the two oscillators are in tune, there is a complete exchange of energy between the two oscillators; there are repeated instants when one stops moving while the other moves with maximum amplitude. The transfer of energy between the two oscillators continues until both amplitudes gradually fall to zero. The position of the mass corresponding to total energy transfer between the two oscillators can be used as the means of measuring that mass.

This balance works on the same principle as that used by astronauts in space when weightless. It is offered here as an educational device for demonstrating inertial mass and for providing a means of measuring it.

Construction

The balance (Figure 2.8) consists of:

(1) A straight length (about 0.5 m) of spring steel wire A, terminating in a helix B (about 12 mm mean diameter) at one end and a rubber stop at the other;

(2) A mass holder M, which is a cylindrical box of low mass with a screw cap to which is attached a boss with a through-hole and clamping screw so that the holder can be clamped along the wire A;

(3) A flat steel spring L (about 0.15 m long, 12 mm wide and 0.3 mm thick). L is held by a clamp parallel to the wire spring;

(4) A clamping strip C that is itself clamped at the helix end of the wire A, and provides the mechanical coupling between the latter and L.

Both the position of C along A and the length of L can be adjusted for different experiments. The balance is supported firmly at B on a rod of 12 mm diameter. The orientation of the balance with respect to horizontal is unimportant. If it is mounted on an articulated joint, it is possible to observe that the behaviour of the balance remains unchanged regardless of its inclination, i.e. independent of gravity.

Operation

To operate the balance, the end of the wire A and hence the mass holder M is displaced from its rest position and then released. As a result the holder will oscillate and so, too, will the flat spring L, but the behaviour of the latter will depend on the ratio of the frequencey of oscillation of L and M, f_L/f_M.

If $f_L/f_M < 1$, the oscillations will be small in amplitude and opposed, i.e. f_L will be about 180 out of phase with f_M. If $f_L/f_M > 1$, the oscillations will be larger and roughly in phase.

When $f_L/f_M = 1$, i.e. both frequencies are the same, L oscillates with large amplitude but 90 out of phase with M. This condition is quite evident, for there are instants when M obviously comes to rest and L vibrates with maximum amplitude; later M will restart to vibrate with increasing amplitude until some instant later L will be at rest with M moving with maximum amplitude (energy). This behaviour will continue until their energy is dissipated; when $f_M = f_L$, a maximum transfer of energy occurs and this is the condition for measurement of mass. With the mass holder at a fixed position along A, inertial mass can be defined empirically, viz:

(1) Two inertial masses M_1 and M_2 are the same if both separately satisfy the condition for maximum exchange of energy;

(2) An inertial mass M has the same mass as $M_1 + M_2$ if both M and (M_1+M_2) separately satisfy the conditions for maximum exchange of energy.

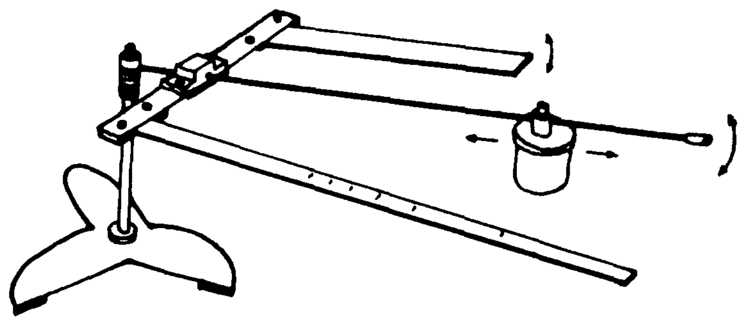


Fig. 2.8 First arrangement of balance: f_L = constant

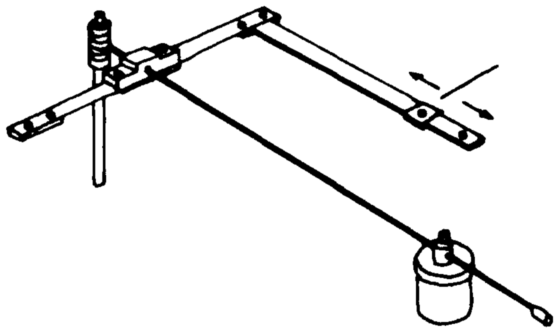


Fig. 2.9 Second arrangement of balance: f_M = constant

The balance is calibrated as follows:

(1) The empty mass holder M is alternately put into oscillation and then moved along A a little until the conditions for resonance, i.e. $f_M = f_L$, are met. This position can be marked on the wire A as 'zero'.

(2) A mass of 1 unit is put into M (e.g. 1 g). The frequency will be lower with respect to f_L so M must be moved little by little towards the centre of oscillation to increase f_M until the required condition is reached. The wire A is then marked '1 unit'. Calibration can be continued with M = 2 u, 3 u, etc, up to 25 g.

It is recommended that paper tape clamped to C be used for the calibration instead of marking A like a steelyard (Figure 2.8).

To measure an unknown mass X, the mass is placed in M, which is then made to oscillate. M is moved along A until the resonance condition is met; the tape is then pulled parallel to A and the mass X read off from the position of the holder with respect to the calibrations.

An alternative method (Figure 2.9) is to make use of the fact that if the position of M is fixed, the frequency of f_M will change with the masses put into it. The frequency of L can be altered by moving a fixed mass Q along its length (a cursor or small magnet is convenient for this) and marking calibrations on paper tape stuck to L. The capacity of the balance described is 25 g, but by increasing the mass of the cursor experimentally, the capacity can be doubled.

Results

Typical results are shown in Table 1 and Figure 2.10. The error of 0.2 cm in measuring the distance corresponds to the interval over which M is observed to come to rest. Because the calibration is not linear, the balance has a varying sensitivity and it is necessary to take account of this when reading a mass from the curve.

Mass/g	Distance along L/cm	Error/cm
0.0	0	—
5.0	11.2	0.2
10.0	16.0	0.2
15.0	19.0	0.2
20.0	20.4	0.2

Table 2.1 Typical results

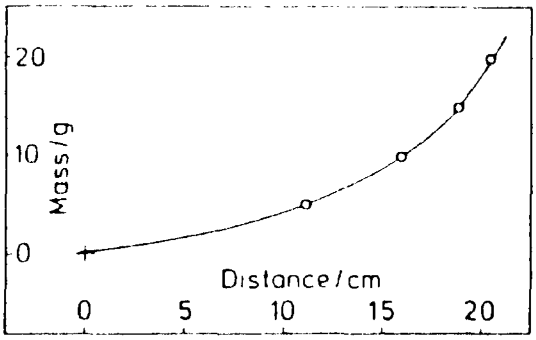


Fig. 2.10 Plot of results shown in table 2.1

XVII. BALANCED DYNAMIC CARTS Herbert H. Gottlieb

The equivalence of inertial and gravitational mass may be shown by tying two dynamics carts together and placing them in the centre of a 3 metre board, balanced on a 5 cm by 5 cm fulcrum, as indicated in Figure 2.11. Burn the string and have the class observe that the system remains in balance as the force of the compressed spring bumpers propels the carts in opposite directions along the board. Adding mass to one of the carts will result in a reduced velocity because of the inertial mass, but the system will remain in balance because the torques developed by the gravitational forces are equal until one of the carts reaches the end of the board.

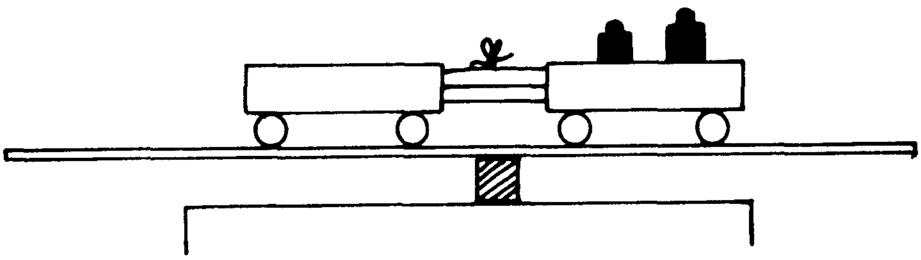


Fig. 2.11 Apparatus for demonstrating the equivalence of gravitational mass and inertial mass. (Not to scale.)

XVIII. A DEMONSTRATION OF MOMENT OF INERTIA

Walter Q. Quint

As an introduction to the concept of moment of inertia it is useful to demonstrate the importance of both mass and the distribution of mass.

This demonstration can be done by using four 500 g masses, two metre sticks, and some masking tape. On one metre stick tape a 500 g mass at the 45 cm mark and a second 500 g mass at the 55 cm mark. The second metre stick should have a 500 g mass at each end.

Select the most petite female student to operate the centre- loaded metre stick and give the end-loaded metre stick to the biggest "football player." Have the students hold the metre sticks at the 50 cm marks and then stand facing each other. Instruct the petite student to rock her metre stick back and forth at increasingly greater speeds. The football player is instructed to simply "follow the leader." As the centre-loaded metre stick is moved faster the football player, with his end- loaded metre stick, will find his effort to be futile. The importance of mass distribution in moment of inertia is obvious.

Commercially prepared "inertial wands" are available but this homemade apparatus is cheaper and makes the situation very visible.

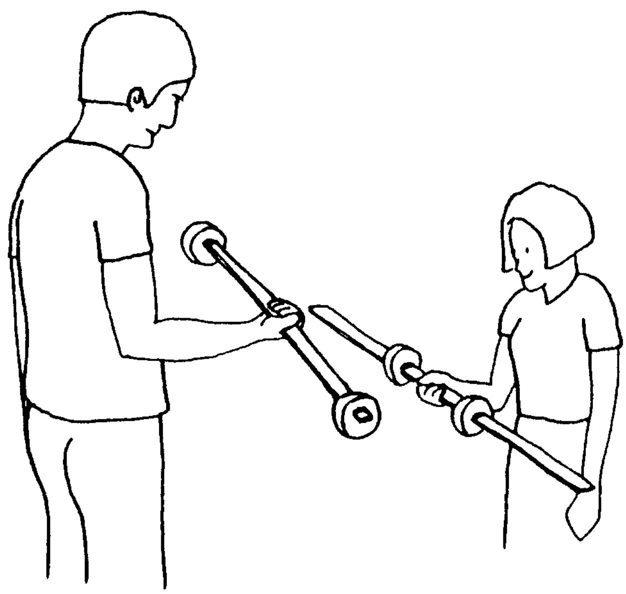


Fig. 2.12 A contest to clarify the concept of moment of inertia.

UNIT 3 MAKING CHANGES

I. EXPERIENCING NEWTON'S SECOND LAW

Project Physics

One way for you to get the feel of Newton's second law is actually to pull an object with a constant force. Load a cart with a mass of several kilograms. Attach one end of a long rubber band to the cart and, pulling on the other end, move at such a speed that the rubber band is maintained at a constant length, for example, 70 cm. Holding a meter stick above the band with its 0 cm end in your hand will help you to keep the length constant.

The acceleration will be very apparent to the person applying the force. Vary the mass on the cart and the number of rubber bands (in parallel) to investigate the relationship between **F**, **m** and **a**.

II. BOWLING BALL PHYSICS

George Amann, Floyd Holt and James Flanagan

A simple F = ma lab becomes more fun when the unbalanced force is provided by a 7 kg bowling ball hung out the window over a pulley, and the mass being accelerated is a student on skates (or two momentum carts). Be prepared to have a great many students want to try this demonstration. You can use it to trigger a discussion of inertial and gravitational mass.

If your tape-timer experiments to measure the acceleration due to gravity don't engender much excitement, let the students try attaching their tape to a bowling ball that is to be dropped from a second-floor window, or the top row of the bleachers. This does use up more paper tape, but is well worth the investment.

III. A FUN EXPERIMENT WITH NEWTON'S SECOND LAW

Walter F. Anderson, Jr. and Leo Takahashi

While preparing for a laboratory for two year technology degree students, we came up with an experiment involving Newton's second law which was fun and straightforward but which has not previously been published. The time had arrived for an experiment to demonstrate this law. Thoughts of Atwood's machines, air tracks, and little carts were floating through our minds. But surely students believe Newton's second law. Hasn't everything else which we have told them been true as proven by us in lecture demonstration or themselves in laboratory? Let's not prove Newton's law! Surely the physics class did that last year; probably even Newton did. Instead why not use Newton's second law to measure the mass of some object?

Once again thoughts of gliders, weights, and pulleys started flying through our minds. No! Stop! Let's get away from this equipment designed mainly for a physics laboratory which the student will most likely never see again and take the experiment to his environment. Yes, it was finally clear: the students should measure the mass of something in their environment by pushing or pulling it with a known force. They could measure the resulting acceleration and calculate its mass with the help of Newton's second law. Probably the object should be something large so it would not accelerate too fast or could not easily be placed on a scale.

A car was the obvious answer. In clear, warm weather a car belonging to one of the instructors, a Datsun 240Z, was chosen. The location of the experiment was one of the parking lots on campus. At other times the object of interest was a laboratory cart, or the instructor's chair. In these cases the experiment was done in the hallway outside of the physics lab. Since all of these objects had wheels, the frictional forces should remain relatively constant and presumably could easily be taken into account.

The general procedure was to do a group experiment with about 16 students. Some rode the moving object marking its location at equal time intervals, others had the tough job of supplying the force, others measured the distance between the marks from which the acceleration could be determined, and still others just stood around giving encouragement.

The force was applied by a student pushing on a bathroom scale or pulling on a spring type scale. The magnitude of the force could be read directly from these scales in pounds and was converted to newtons. This was probably the most difficult part of the experiment in terms of experimental skill required by the student. The scales generally had little damping and therefore tended to oscillate quite a bit. Students also had the natural tendency to push or pull with less force as the speed increased. But after the instructor had pointed out these problems they generally kept the average force relatively constant to the maximum speed of the object. Care had to be taken to push or pull horizontally.

The frictional force in the bearings was measured by finding the applied force which was necessary to keep the object moving at constant velocity. This force was found to be independent of velocity in the range of velocities for which data was taken and therefore was simply subtracted from the applied force in each case to find the actual force causing the acceleration of the object. Data was only taken after things "got moving" smoothly. By doing the experiment on a parking lot with constant slope, the effect of friction was either partially or totally counteracted by gravity, and pushing to obtain a reasonable range of speeds was somewhat easier. If the grade was too large, the parking lot was transversed at an angle such that the car drifted at constant velocity with no applied force. In this case it was not necessary to measure the frictional force since it was canceled by the force of gravity.

The acceleration was found from measurements made of distance vs time. In most cases the students already had done a free-fall experiment and therefore were fairly familiar with interpretation of position vs time data. The experimental choice was either to measure the position after equal time intervals had elapsed or the time after which the body had traveled equal distances which had previously been laid out. Both were used; the first choice worked out best.

Many methods were used for timing. The best method was to have some type of timer riding with a student on the object. At equal time intervals the student marked the position of the object on the road or floor using a can of spray foot powder. A cheap and convenient timer is a metronome, the metronome being calibrated over long time intervals with a watch. Sometimes a mechanical metronome was used; at other times an electronic metronome which was constructed from a commercially available kit(1) was used.

The time intervals were chosen as 1 sec and the average velocity during each time interval was simply the distance traveled divided by 1 sec. Graphs of velocity vs time were subsequently quickly plotted as shown for several forces in Fig. 3.1. By measuring the slope of each line the acceleration resulting from each force was obtained.

The net force and the resulting acceleration were plotted as shown in Fig. 3.2. The slope of this graph was the mass of the car plus occupants which in this case was found to be 1180±120 kg. The total mass of the car from the manufacturer's specifications and the mass of the occupants was 1235±25 kg.

Generally the data scattered quite a bit on the graph due to the errors involved in the measurements of times and forces. For example, the scale could be kept constant only within ±0.5 kg. If the accelerating force was 5 kg, then this force was varying by 10%.

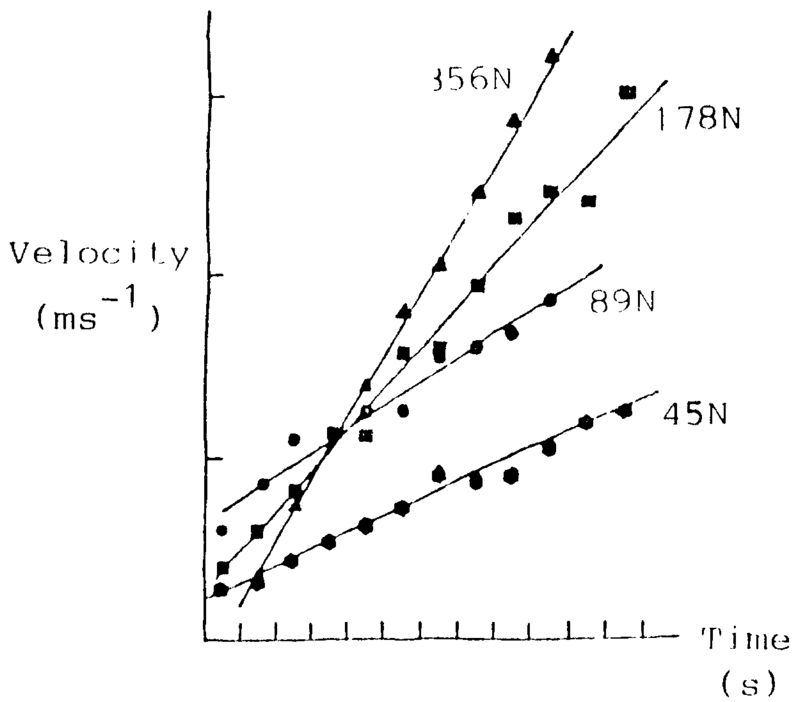


Fig. 3.1. The velocity of the 240Z as a function of time for various accelerating forces. The experiment was performed at such an angle in the parking lot that the force of gravity balanced the frictional force.

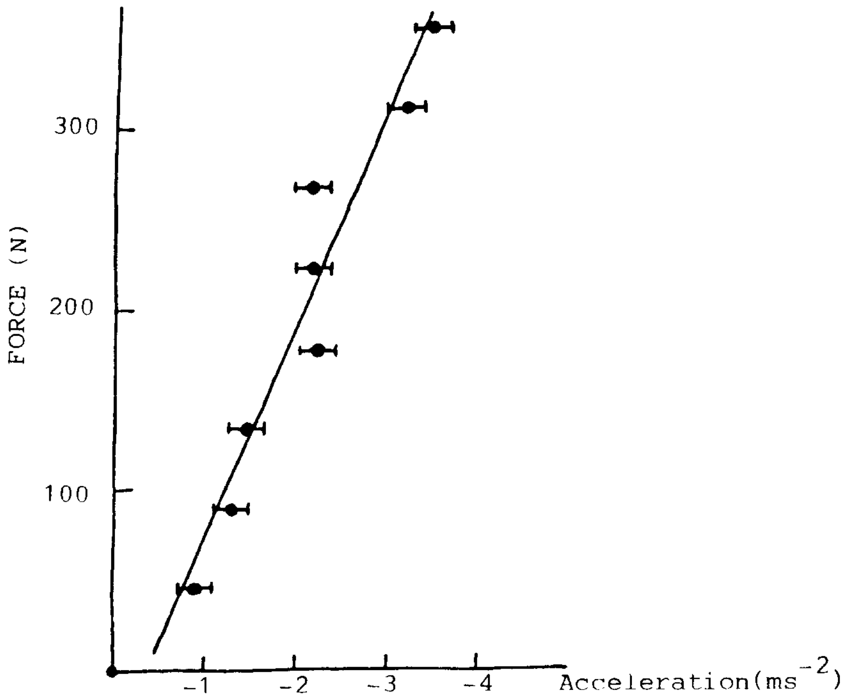


Fig. 3.2. The acceleration obtained from the slope of each line in Fig. 3.1 is plotted against the accelerating force. From the slope of this line the mass of the 240Z was calculated.

Many students did not know what to do if the points on a graph did not line up in an obvious straight line. Most teachers have a tendency to have students do experiments with errors of a few per cent so when plotted on a normal graph sheet the data "looks good," that is, does not have much scatter. We suspect this has arisen partially from their desire to have the student convince himself that some physical law is true or that a measured quantity is correct. After plotting his data on a notebook-size sheet of paper and obtaining a practically straight line of points moving across the page, he certainly would have no trouble in concluding that the law was indeed correct. How surprised he might be if he plotted his points on a 1 m by 1 m graph so all the class could share in his joy? Experiments with more scatter than students are exposed to in physics classes continually pop up in research situations every day. Certainly many original decisive experiments have involved some guessing on the part of the investigators due to random error spread in their data. This experiment is an excellent occasion to bring up this subject.

How accurate was the value of mass obtained: ± 5 kg, ± 50 kg, ± 500 kg? Most students suggest weighing the car and passengers and comparing the value they obtain with the value arrived at in their experiment. What if scale are not available? This brings up the subject of judging the errors involved in the experiment itself and the resulting error they cause in the calculated mass.

We have done this experiment in different courses spanning from physical science to calculus level general physics. In every case it was successful. The experiment was done during a one-period physical science lecture with the students individually plotting their own graphs under the close guidance of the instructor. They already had done a free-fall experiment so the plotting of graphs and their consequent interpretation were part of the student's background.

The students and instructors really enjoyed this experiment. There was a lot of action and many fun things to do. As has been recently reported, (2) the use of cars is quite popular. The students had a chance to associate the ideas they were learning with their immediate environment and interests. There is really a lot of physics to be learned with this kind of experiment.

References

1. Available from Allied Radio Shack, 100N. Western Avenue, Chicago, IL 60680; Science Fair Kit £28B118.
2. Robert J. Kenney, Phys. Teach., 12, 491 (1974).

IV. AN IMPROVED NEWTON'S SECOND LAW EXPERIMENT F.E. Domann

One of the most important and elementary ideas to be demonstrated with real laboratory apparatus is Newton's second law. Too frequently it is demonstrated with the aid of strings, pulleys, etc., which for the sake of simplicity are assumed massless or frictionless. Although improvements to the Atwood machine have been made(1), this department has developed an experiment that appears to be simpler, more direct, and effective. A schematic diagram of the apparatus used is shown in Fig. 3.3 The air track is inclined at some small angle, usually about three or four degrees. The glider is outfitted with a specially made frame that supports a small plastic pulley and a spring scale that is calibrated in Newtons. One end of a long string is attached to the spring scale, and the other is attached to a mass that is allowed to drop as shown. Thus the forces acting on the glider are measured directly. The force acting down the plane, i.e., the $\sin\theta$ fraction of the glider's weight, can be measured by either (a) adjusting the hanging weight such that the glider moves up the plane with constant speed or (b) simply by holding the glider at rest on the incline. In either case the $Mg\sin\theta$ fraction of the glider's weight is simply read off the scale. When the hanging weight is increased, the force acting up the incline, F, is read off the scale directly, and then the net force acting up the plane is $F-Mg\sin\theta$

1. L. Cintra Do Prado, Am. J. Phys. 38, 541 (1970).
2. N. Naba, Am. J. Phys. 42, 409 (1974).
3. H. V. Neger and R. B. Leighton, Am. J. Phys. 31, 255 (1963).

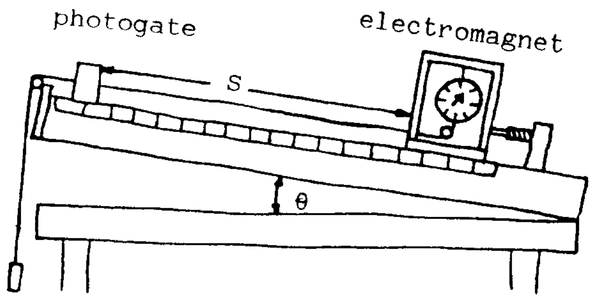


Fig. 3.3. Schematic drawing of the air track and glider system.

Now ideally, the instantaneous acceleration of the glider as well as the forces acting on it would be measured directly using one of several methods described previously.(2, 3) However, in an attempt to keep the apparatus as simple as possible, we have chosen to determine the acceleration indirectly by simply measuring the time t required for the glider to accelerate from rest through a predetermined distance S.

The acceleration of the glider is then given by

$$a = 2S/t^2 \qquad (1)$$

The time can be measured with either an ordinary stop-watch or a photogate timer. The glider can be released from rest either with a finger, or an electromagnet. If an electronic stopwatch is used as shown in Fig. 3.3, it is convenient to use a double pole switch that activates the timer and turns off the electromagnet simultaneously.

Having obtained a set of force-acceleration data, one can test Newton's second law by plotting the force F versus the acceleration a. For a frictionless inclined plane Newton's second law predicts that

$$F = Ma + Mg\ \sin\theta \qquad (2)$$

If one wishes to include frictional effects one writes

$$F = Ma + Mg(\sin\theta + \mu\cos\theta) \qquad (3)$$

In either case the F versus a graph should be a straight line with a slope equal to the mass of the glider.

Figure 3.4 shows the graph of a typical set of data, and has a slope of 1.12 $\pm$0.08 kg. The mass of the air glider measured with a laboratory balance was 1.23 $\pm$0.02 kg. The coefficient of friction between the air track and glider is negligible, and the acceleration of gravity can be found from the intercept of graph. For the data shown in Figure. 3.4, the angle of include was 3.4^o. Thus the intercept of this graph yields a value for g of 9.76 ms^{-2}. The results are remarkably good despite apparent crudeness of the spring scale used.

The expected accuracy of the results of course depends upon the uncertainty in the data. Using a meter stick and a photogate timer, the quantities s and t [Eq. (1)] can readily be measured to within 0.5% each. Thus the relative uncertainty in the acceleration can be estimated by

$$\Delta a/a = [(\Delta s/s)^2 + (2\Delta t/t)^2]^{1/2} = 0.011.$$

More significant is the uncertainty in the force measurement, F, which depends heavily upon the type and condition of the scale used. The scales used in our laboratory are general purpose 2.5- N, spring dial, Sargent-Welch scales. A clean, lightly oiled scale of this type gives a reproducible force measurement to within 0.025 N. This uncertainty in F is shown with error bars in Figure 3.4.

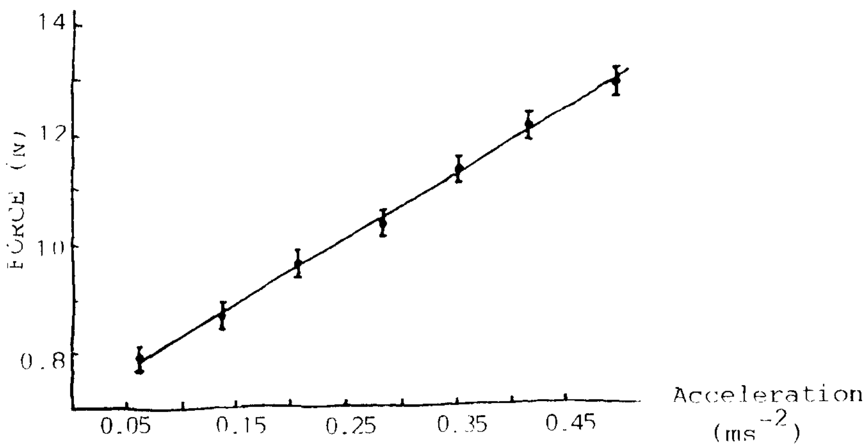


Fig. 3.4. Graph of force versus acceleration from an actual set of data. The slope of this line is the mass of the glider.

Thus this experiment seems to adequately demonstrate Newton's second law in a very straightforward way and, we feel, offers two important bonuses: (a) because the air track is inclined, there are two readily identifiable forces acting on the glider, giving recognizable meaning to ΣF and (b) by simply watching the scale needle decrease when the glider is released, students begin to understand the concept of unbalanced forces. This latter point is very important. After all, one of the most nagging difficulties for beginning students studying dynamics is to realize that the tension in the cable for a falling elevator is less than mg!

Acknowledgments

Thanks are due to everyone in our physics department that contributed to this project, especially Burke Huner.

V. FREE FALL USING AUDIO RECORDING TAPE

Charles Rudisill

The Pohl free fall apparatus(1) operates by dropping a long paper-covered cylinder past a leaky ink cartridge that is rotated by a 1700 rpm motor. The distances between the ink spots are then measured and analyzed to determine the acceleration of gravity. It is suggested that a strip of audio tape recorder tape be used in place of the paper cylinder and that a small bar magnet be substituted for the ink cartridge (Fig. 3.5). As the magnet spins, the tape will be magnetized strongly each time one of the poles approaches. If the magnet is placed off center and counterweighted, the period between magnetizing pulses will be twice as long. After each trial, the tape can be examined by sprinkling iron filings over its length. Some filings will stick to the portions that are strongly magnetized. To overcome air resistance, it will be necessary to attach a weight to the bottom of the tape as shown in the illustration.

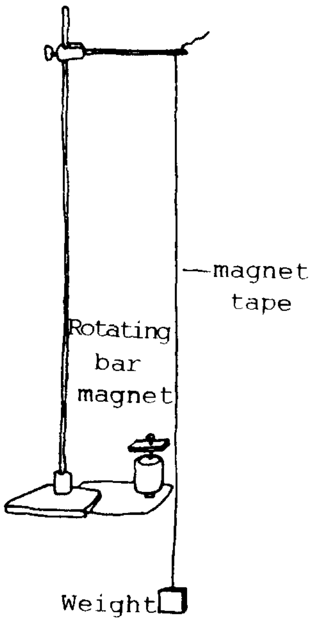


Fig. 3.5. Tape is magnetized as it falls past a rotating bar magnet.

1. Pohl's Free Fall Apparatus, KM1051, Klinger Scientific Apparatus Corp., 83-45 Parsons Blvd., Jamaica, N.Y. 11432.

VI. CHRONOLOGY OF HISTORICAL, SCIENTIFIC AND TECHNOLOGICAL EVENTS

W. Williamson, Jr., W. Williamson, III, and W. Williamson, Sr.

Quite often when a high school or lower division college student is taking a course in physical science or physics, little if any time is devoted to paralleling historical events, technological achievements, and scientific advancements. The student normally finds it difficult to tie the things he has learned in one course together with those in another one simply because the courses are taught separately. Distributing a chronology to the students helps to alleviate the problem.

A sample page of our chronology is presented here and a limited supply of the complete chronology is available by writing to W. Williamson, Jr. at the University of Toledo. We have used the chronology in natural science and elementary physics and find that students enjoy reading through it and begin to appreciate how history, science and technology are interwoven. The chronology does not pretend to be a definitive work and several events listed under one title heading could equally well be listed under another heading. While some events we have listed may be considered interesting trivia, we hope nothing of major importance has been left out. If so, we would appreciate knowing about it.

Finally, we would like to state that during our search through the literature for data to make this chronology, we found numerous disagreements between sources about dates. We would like to dodge any debates by simply saying that all dates in this chronology should be regarded as approximate dates.

A sample page of the Chronology

DATE	HISTORICAL	SCIENTIFIC	TECHNOLOGICAL
1619		Kepler's third book published. All three laws of planetary motion known. He was a former student of Brahe.	
1620	The Mayflower's trip to Plymouth		Oughtred invented the slide rule
1621		Snell's law of refraction	
1626	Francis Bacon died		
1633		Galileo put under house arrest	
1636		Romer estimated the speed of light	
c.1637		Descartes and Fermat	
1638	Japan closed to Europeans until 1865	Galileo, "Two New Sciences"	
1642	Rembrandt painted the "Night Watch"	Newton born (same year as Galileo died)	Pascal invented the first mechanical machine for addition and subtraction (also credited with the one-wheel wheel-barrow)

1643			Torricelli invented the barometer
1648		Discovery of the atmosphere (Galileo, Torricelli, Viviani and Pascal)	
c.1665			Von Guericke invented the vacuum pump
1657		Huygens wrote the first formal work on probability theory	
1661		Boyle, "Sceptical Chymist"	
1662		Royal Society founded	
1665	The Great Plague in London		
1671		Newton and Leibnitz developed the Calculus	
c.1671			Leibnitz invented a calculating machine which could multiply

VII. SPRING-WOUND TOY CARS - EXPERIMENTS IN MECHANICS

Charles Hanna

Are you tired of rolling PSSC dynamics carts down an inclined plane to obtain data for an acceleration experiment? The new spring-wound toy cars lend themselves to a large number of experiments in mechanics.

My physics students this year studied the kinematics of four such cars and their response was truly enthusiastic. The four cars studied were:

1. The **Power Dash** (toy stores)
2. The **Speed Burner** (toy stores, K. Mart, or Osco drug stores)
3. The **Scorcher** (toy stores or K. Mart)
4. The **Darda** car (toy stores, Woolworth's, Sears Roebuck and Co. Christmas Catalogue, or direct from the Darda Toy Co., P.O. Box 160, East Brunswick, NJ 08816)

There are other competing brands. The **Wrist Racer** is a current best seller. You will also need several meters of inexpensive plastic track.

These toy cars are powerful motivators in the classroom. They are virtually indestructible, they are very cheap ($2 - $4), and they come in a variety of bright colors and models. In addition, they give quite reproducible results and they are very, very fast. The accelerations of these toy cars must be seen to be fully appreciated.

On the first day of our unit on kinematics I merely set some of the cars on my desk. Before the opening bell has sounded the students are running them across and over the edge of my desk and into the walls of my classroom. How quickly one forgets that high school physics students (and teachers) are kids at heart! The difference between uniform and accelerated motion is discussed. The cars are then put away for a few days while the students perform the Project Physics experiment, "Measuring uniform motion." For those unfamiliar with the experiment, students take a strobe-light Polaroid photograph of a moving, low-friction disc or air-track glider, construct a distance-time graph, and analyze their data to determine if the speed is, indeed, uniform.

An acceleration experiment

I generally preface the experiment by challenging some of the more automobile-oriented students in class to a proxy drag race. The claim is that these toy cars can out-accelerate anything the students themselves drive - not scaled down but absolute acceleration! Most students are skeptical but some serious eyeballing of a Speed Burner ripping down the track proves a bit unsettling to the owner of a fuel injected Dodge Charger.

For postlab comparison purposes some of the students are asked to construct a velocity-time graph for the family car. (One student drives and a passenger records the velocity from the speedometer every two or three seconds. See Fig. 3.6.) I admonish them not to burn excessive amounts of rubber. Judging by some of their graphs, my warning is occasionally (predictably) ignored. I have had students collect extremely accurate data using a calibrated Project Physics blinky in their car photographed at night.

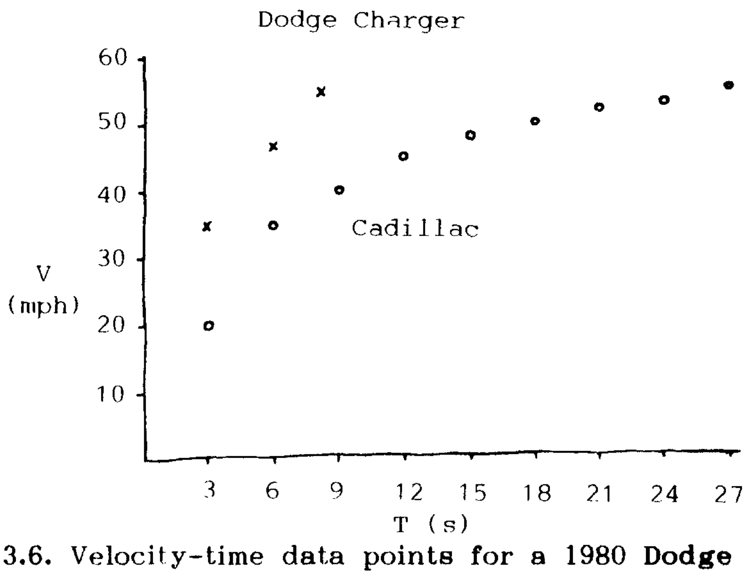


Fig. 3.6. Velocity-time data points for a 1980 Dodge Charger and a 1980 Cadillac Coupe de Ville. Curves have not been drawn because of the great (and unknown) uncertainty of the data.

It should be pointed out that even if one decides against using these toy cars in the classroom, construction of a velocity-time graph for a real car is a dandy little take-home experiment. When slopes of these graphs are compared on the overhead projector, students seem to get a better quantitative feel for acceleration. For instance, the data of the initial three-second interval for the Dodge Charger of Fig. 3.6 yield an average acceleration of a little less than 12 mph/s (5.4 ms^{-2}). Remember, when one takes velocity readings from a moving automobile speedometer at three-second intervals, one obtains only a gross outline of the car's motion; detailed analysis is not possible.

For reference, here are some other very quick accelerations, copied from the 1980 Guinness Book of World Records:

1. Porsche 924 Turbo: 0 - 30 mph in 2.3 s (first gear).
   a = 13 mph/s (5.8 ms^{-2}).
2. Kawasaki motorcycle: 0 - 180 mph in 7.09 s.
   a = 25.4 mph/s (11.4 ms^{-2}). (Note that this exceeds the acceleration due to gravity, which is 22 mph/s.)
3. Craig Breedlove in the rocket-powered English Leather Special on the Bonneville Salt Flats: 0 - 377.754 mph in 4.65 s.
   a = 81.2 mph/s (36.3 ms^{-2}). (almost 4 g's)

Returning to the classroom, the toy cars are then used to perform the standard kinematics experiment on acceleration. Data is obtained from Polaroid photographs taken under a strobe light. We tape small soda straws to the cars for ease in analyzing data. PSSC timers with paper tape can also be used. However, if one desires the true acceleration, the timers must be calibrated.

Velocity-time graphs are constructed and compared on the overhead projector. Figure 3.7 shows the results of the race photographed. The accelerations are approximately constant for the first 0.5 s (0.6 m) and then decrease. If the springs inside the cars do, indeed, obey Hooke's law and the wheels do not slip on the track, the force and, hence, the acceleration should decrease linearly with distance. It seems likely that the early constant acceleration is merely the upper limit imposed by slipping of the drive wheels. The top speed we recorded for any of the toy cars was 6.7 ms^{-1} (15 mph) and the top acceleration recorded (Speed Burner) was 5.50 ms^{-2} (12.3 mph/s or over 1/2 g!)

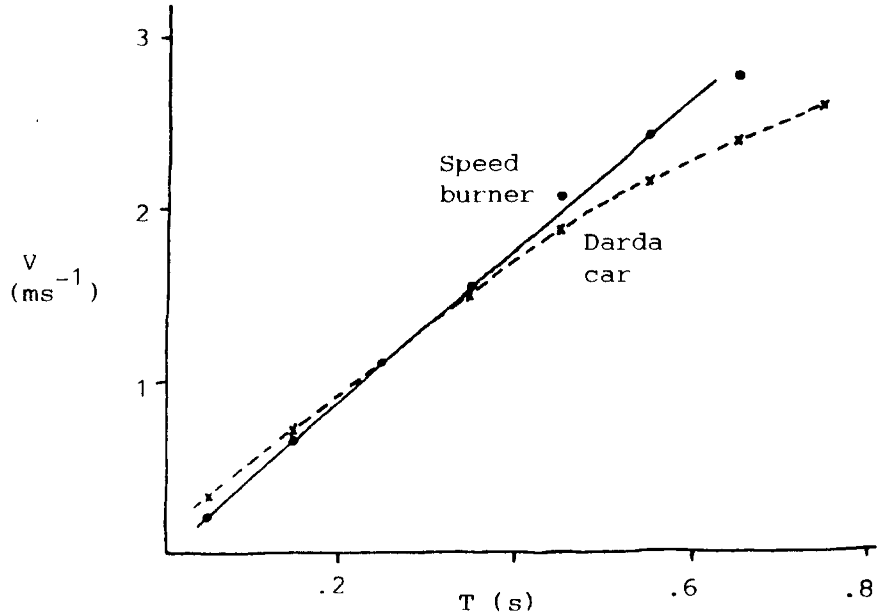


Fig. 3.7. The results of the race: the **Speed Burner** (solid line) versus the **Darda** car (dashed line).

To complete the experiment, the cars are raced side by side in single elimination fashion to verify the theoretical order of **finish.** Finally, the fastest toy car can be compared to one of the students' gas hogs. The **Speed Burner** above (a = 12.3 mph/s) is seen to nose out the student's **Dodge Charger** from Fig. 3.6 (a = less than 12 mph/s). A word of caution: The toy cars will out- accelerate a real car over 90% of the time. However, a very quick **Porsche, Corvette,** or **Dodge Charger** will usually beat out the toy **Speed Burner** so don't wager too heavily on the outcome.

Extensions to the acceleration experiment

1. All of the usual analysis of data associated with a traditional acceleration experiment can be performed with the toy cars. Areas under velocity-time and acceleration- time graphs can be compared to actual distances and velocity changes, respectively.

2. If one decides to forego the acceleration experiment as outlined, I have found that the toy cars lend themselves to a nice quantitative demonstration in determining acceleration. A car is allowed to accelerate down a lengthy stretch of track. The final velocity is determined with the aid of a photogate. The total elapsed time can be determined with reasonable accuracy with a stopwatch. Acceleration is computed in the usual manner: $a = \Delta v / \Delta t$. The data given on the next page was taken for the **Darda** car.

$$v_i = 0$$

$$v_f = \frac{\text{length of car}}{\text{time through photogate}} = \frac{0.069 \text{ m}}{0.012 \text{ s}} = 5.8 \text{ ms}^{-1}$$

$$\Delta t = 1.9 \text{ s}$$

$$a = \frac{\Delta v}{\Delta t} = 3.0\ ms^{-2}$$

My scaler reads to 0.001 s so one can see that the 0.012 s required for the car to pass through the photogate introduces a large amount of uncertainty. In addition, one may compare the actual distance traveled to the theoretical prediction from the distance formula:

$$d = v_0 t + 1/2at^2.$$

This is not actually valid due to the non-uniform acceleration, but surprisingly good agreement is obtained.

Additional experiments with toy cars

One may use these spring-wound toy cars in a variety of other experiments in mechanics.

1. It is instructive to demonstrate the effect of mass on acceleration in Newton's second law. Load increasing masses upon one of the cars and note the decreasing accelerations. With 100 g loaded on top of the **Power Dash** van, the acceleration is agonizingly slow.

The slopes of the graphs of Fig. 3.8 were taken to determine acceleration. Substitution in Newton's second law yields

$$\text{car alone} \qquad m_1 a_1 \overset{?}{=} m_2 a_2 \qquad \text{car} + 50\ g$$

$$0.0441\ kg \times 4.60\ ms^{-2} \overset{?}{=} 0.0941\ kg \times 2.15\ ms^{-2}$$

$$0.203\ N \approx 0.202\ N$$

Evidently, the complex force of friction can be ignored.

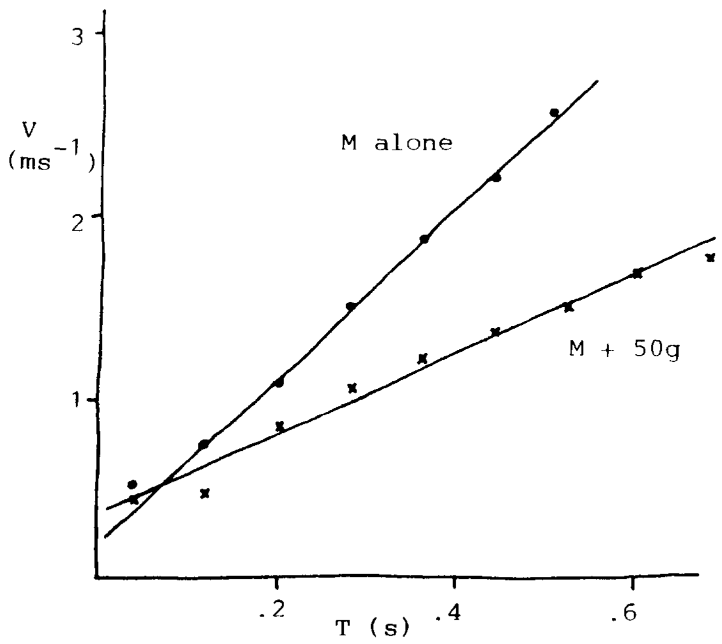


Fig. 3.8. Newton's second law - the effect of mass on acceleration. The velocities of the Scorcher van unloaded, 44.1 g, and the same car loaded with the additional 50 g

2. Circular motion can also be demonstrated. The loop-the-loop and banked turns accompanying the Darda car are class favorites. Textbook problems seem a bit more real when a Darda car goes flying through its turns. We know of no experimental way to determine the centripetal force exerted by the track. The mathematical level of presentation is open-ended.

3. The Project Physics experiment, "Curves of Trajectories", can be easily performed with the toy cars. Data can be obtained from a Polaroid photograph (similar to fig 3.9) and the usual analysis of velocity components follows. If desired, one photograph can be used for an entire class. Simply punch pinholes in the photo, place it on the overhead projector, project it on the chalkboard, adjust the distance to the board for proper scale, and have the students mark and tabulate the ensuing positions.

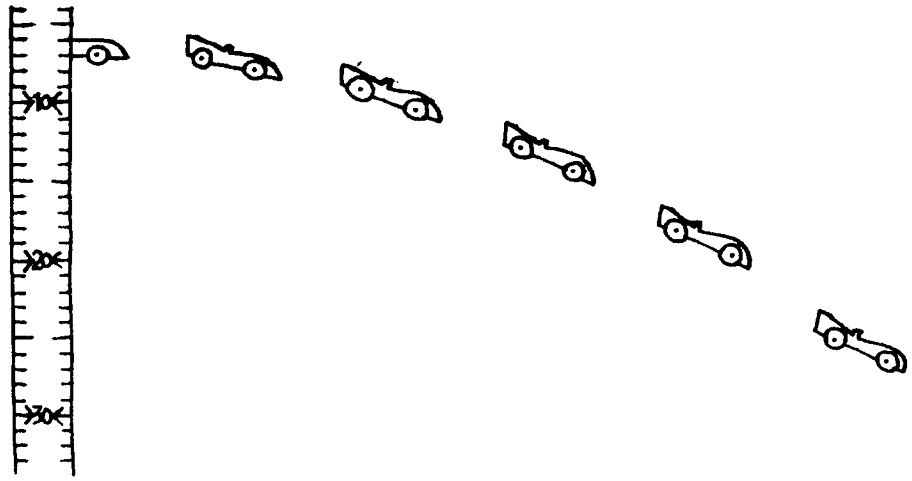


Fig. 3.9. The **Darda** turbo as projectile. The flash rate was 25 s^{-1}.

4. The efficiencies of the various toy cars can be computed. A Newton spring scale is attached to the car and the car is pulled across the lecture table until its spring is fully wound. Work input is then computed from **W** = **F·d**. Depending upon the particular car under investigation, a small mass may have to be added to the car to engage the engine spring during winding. The force is not constant (Hooke's law again) and one must arrive at an average force. The final kinetic energy is computed from **KE** = 1/2 **mv**². One must determine the point at which the car reaches its maximum velocity before decelerating. This is not difficult. A careful visual inspection of the run can locate this point to within 50 cm. Or, manually stop the car at ever greater distances and merely lift it up to see if any energy is still stored in the spring. The final velocity can be determined in any appropriate manner: photogate, strobe photo, or, as a last resort, a stopwatch. The calculation of efficiency follows easily. The data below was taken from the **Darda** jeep.

$$\text{Efficiency} = \frac{\text{final kinetic energy}}{\text{work input}}$$

$$= \frac{1/2 \times 0.033 \text{ kg} \times (5.1 \text{ ms}^{-1})^2}{1.5 \text{ N} \times 1.4 \text{ m}}$$

$$= 20\%$$

Of course, I do not do all of these experiments with a single class during the year. Like other teaching strategies, one does not want to overuse an effective device so that it becomes, "Ho- hum, here come the toy cars again."

I have found the introduction of these spring-wound toy cars into my classroom to be extremely effective. Ask your students to bring them in. If you have never used them before you will be initially impressed by their speed and subsequently by the large amount of mechanics that can be taught with these cars. Students really enjoy them. The following are typical quotes:

"Where did you get these?"
"I never had cars like this!"
"Are these yours or the school's?"
"Do you cruise toy stores?" (Yes, about twice a year.)

In summation, these spring-wound toy cars are a lot of fun and they teach a large body of good physics.

Start your engines!

VIII. NEWTON'S SECOND LAW

Alan Ward

I have found an amusing illustration of Newton's second law of motion: **That the acceleration of a body is proportional to the force acting on it and inversely proportional to the mass of the body.** My 'body' in question is a plastic toy fish (common in toy shops for about 99p) that can swim by clockwork.

The first part of the law is easily shown by giving the winder two turns and letting the tail flap, then comparing this action with what happens after the winder is turned four times. Obviously the greater assumed force (from a tighter spring in the mechanism) produces faster motion. The second part of the law says that a given force should accelerate a small mass faster than a big one. To show this I give the toy four turns on the winder, before holding the greater mass of the body, letting the force of the motor drive the lesser mass of the tail. The tail flaps very fast indeed. Then I repeat the activity whilst I hold the tail. This time what I assume to be an equal force (from four winder turns) produces a sluggish floppy motion of the more massive body.

As an after thought I can wind up the fish again and put it down on the table, where it works noisily, lying on its side, slightly rotating (Newton's third law, the one about reaction ...). Yes, finally, the laws can be studied again--with, perhaps, deeper insight, when the little fish is actually allowed to swim!

IX. THE PHYSICS OF TOYS

H. Levinstein

The fact that force represents time rate of change in momentum may be illustrated with a Newtonian Nutcracker (Fig. 3.10), which may no longer be available but is easily reproduced. A fairly large steel ball is dropped in a plastic tube onto a nut which rests on a brass base. The nut is shattered. When the brass base is replaced by a cushioned base, the nut does not break.

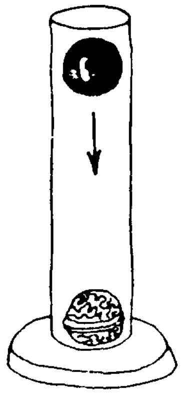


Fig. 3.10. Newtonian Nutcracker.

X. H.F.Meiners (Editor)

Double-stick tape (1) (1.5 mm thick) and a small piece of 0.5 mm-thick Teflon sheet (2) provide a low-friction surface for string passing around a corner, as shown in Fig. 3.11.

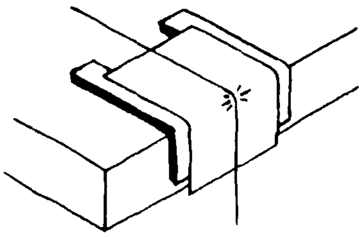


Fig. 3.11.

(1) Available from Behr-Manning Corporation, Watervliet, New York.
(2) Available from Forest Products, Inc., Cambridge, Massachusetts.

XI. ACCELERATION THAT IS NOT CONSTANT

Nuffield O-level Year 4

Lay a length of chain on a smooth table; stretch it out at right angles to the edge (figure 3.12). Pull the end a little way over the edge until, on release, the whole chain slides. Then the hanging portion pulls the rest with increasing acceleration until it is all falling freely. Watch the motion.

To obtain a record, arrange a timer so that the upper end of the chain on the table pulls the tape through.

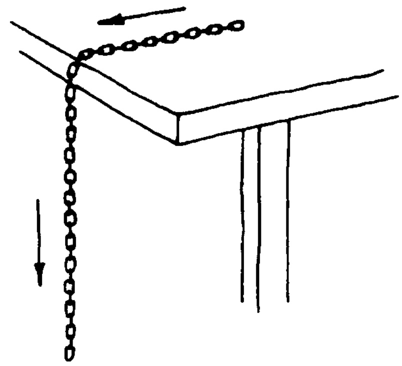


Fig. 3.12

XII. LINEAR AIR TRACK FOR £2

C.W. Stewart

A major difficulty experienced in making a do-it-yourself air track is the breaking of the fine drills used in drilling the air holes in a metal track. By using 62 mm square section plastic downpipe for the track the drilling can be carried out easily and quickly.

A 2 m length of the pipe can be purchased from a building supplier for about £1. 1.5 mm holes are drilled at 12 mm centres on two adjacent sides along lines drawn 10 mm from the corner. Riders are constructed from thin aluminium or thin perspex.

This leaves £1 in hand to buy a car heater blower unit from a local scrap yard. This can be attached to the pipe by a plastic sleeve. Although nominally 12 V, the blower will run without overheating at 16 V from a labpack and give a plentiful supply of air.

XIII. LOW COST AIR TRACK

Thomas Mitchell

A low cost air track can be built from a 5 cm square, 2 mm thick piece of hollow aluminium, 3.3 m long which can be purchased from an aluminium products company.The cost of the aluminium tube-$34.

Because of the number of holes to be drilled, a 0.5 mm bit was chosen. It not only lasted longer but seemed to be the right size hole for both glider support and least amount of air loss due to the length of the tube. The holes on both sides are spaced 25 mm apart longitudinally, and from the top at a 35° diagonal 7 mm, 16 mm and 25 mm apart. This allows exact spacing for a 30 cm Cenco glider.

The ends are sealed with a piece of metal into which a 12 mm pipe is fitted. Two Cenco £74873 air blowers are needed, one at each end. This type of blower is much more compact and easier to handle than the large shop type usually associated with this size air track. Also, one blower can be turned off to have some adjusted air flow.

V-shaped blocks support the air track and are also used for leveling, or desired inclinations, by placing wedges under the blocks.

Two V-shaped blocks are mounted at the ends of the tube and spring bumpers are attached. Tape used for the sealing and mounting of the bumpers is asbestos tape.
The total cost of the air track including blowers, is $130. XIV

XIV. APPARENT 'WEIGHTLESSNESS' — Nuffield O-level Year 4

See Figure 3.13. A kilogram is placed on the weighing scale which shows the pull of the Earth on that load. Watch while scale and load fall freely.

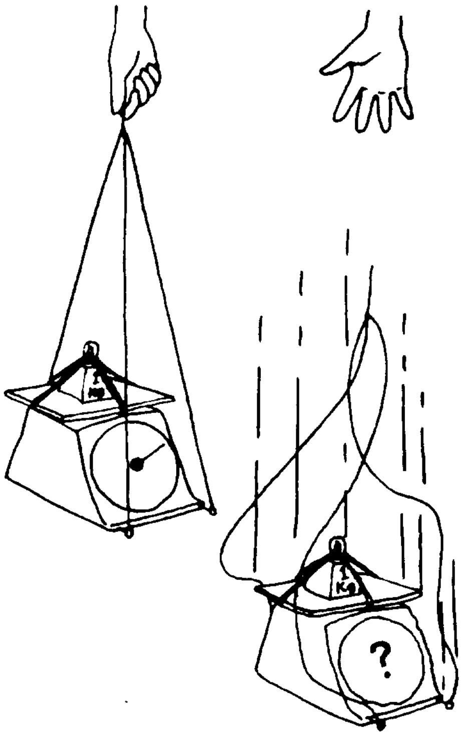


Fig 3.13

XV. FULL-SCALE DEMONSTRATION OF ACCELERATION — Jack A. Soules

Many colleges and universities, particularly those in large cities, now boast of high-rise buildings equipped with modern high-speed elevators. Such an elevator is an ideal laboratory for a physics student to perform entertaining and instructive experiments on acceleration. The only additional apparatus required is a bathroom scale and a stopwatch. Even the stopwatch can be dispensed with.

Riding an elevator on a bathroom scale quickly and dramatically calls attention to the fact that acceleration is a vector quantity independent of velocity; upward velocity can be accompanied by upward or downward acceleration and vice versa.
The acceleration experienced in elevators will range from 0.1 to 0.3 g and will last from 1 to 4 s depending on the height of the building (and the cruising speed of the elevator). In the elevators I have ridden the

magnitude of the acceleration is about the same whether starting up, stopping (up), starting down or stopping (down). Most bathroom scales are slightly under- damped but will settle down to give a good force reading in 1 or 2s The experiments provoke instant understanding in the students performing them. They also draw a crowd of interested spectators who want to try for themselves. Some have even been heard to remark that if this is what physics is about they would like to take the rest of the course!

Following my own and my students' experiments and the decision to write this note, I had a pleasant interview with Mr. Anthony Secresty, Regional Field Engineer with the Otis Elevator Company. Mr. Secresty confirmed the experimental results we had obtained and offered some additional comments on elevator engineering. Elevator speeds range from 0.5 to 7 ms^{-1}; a majority of high-rise passenger elevators have cruising speeds of 2-3 ms^{-1}. Various systems are used to provide a comfortable ride (uniform or constant acceleration up to cruising speed) and maximum traffic flow. The Otis elevators, which are installed throughout the world, use dc motors with multiple windings switched in or out in sequence to maintain approximately constant acceleration and deceleration. Mr. Secresty provided data for the accompanying graph of performance of a typical Otis car.

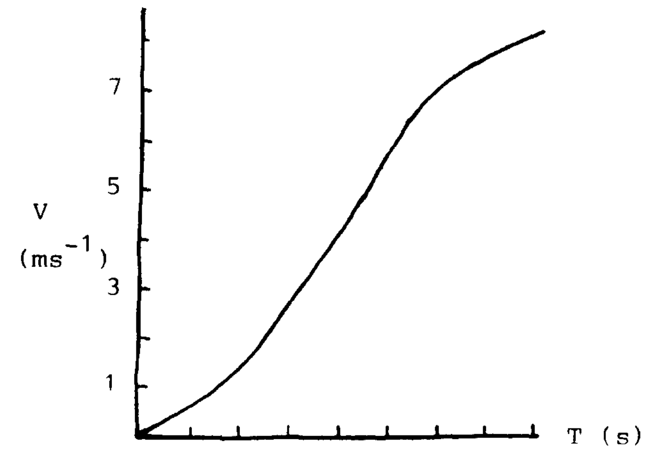


Fig. 3.14. Velocity is plotted as a function of time. The slope at t = 1.5 s corresponds to an acceleration of 0.17 **g**.

XVI. FORCE OF A JET

W.K. Mace

Experimental investigations of **F** = m**a** have always been standard procedure in school laboratories. When the law is generalized to **F** = d**p**/dt, however, with particular reference to 'mass per second x velocity change', there is a dearth of simple confirmatory experiments.

The diagram illustrates an arrangement which is no trouble to set up and seems to be reliable to within two or three per cent. About 45 cm of 4-mm glass tubing is bent to a right angle at one end and pivoted from a boss head by the rubber tube which connects it to the water tap. Without the weight of the large rubber bung, a moderate flow of water causes the end to rise in the air. With the addition of the bung a spring balance can be used, as shown, to measure the reaction force arising from the imparting of vertical momentum to the stream of water.

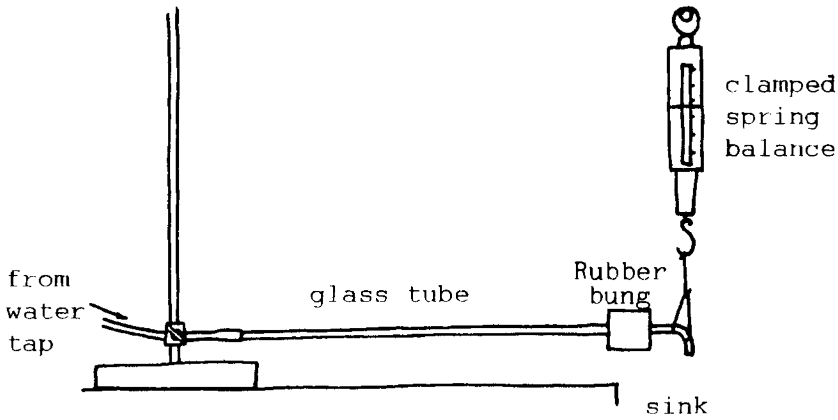


Fig 3.15

The mass per second is found by weighing after 10 seconds' collection in a litre beaker, and the velocity is obtained by measuring the bore of the tube. A quick and surprisingly accurate value for bore diameter can be obtained by using a long demonstration magnet needle as a wedge gauge. It is gently inserted until it touches both sides, withdrawn with a thumb-nail marking the depth of insertion, and measured with a vernier caliper.

Typically, a flow of 60 cm^3s^{-1} gives about 30 grams-force reaction.

XVII. THE MOMENTUM BALANCE: A DEMONSTRATION OF NEWTON'S SECOND LAW OF MOTION

G. Giles

There are many experimental methods of verifying that **force = mass x acceleration.** The apparatus described in fig. 3.16, which was exhibited at the London Meeting, demonstrates the original form of Newton's Second Law of Motion:

force = rate of change of momentum

Construction

The jet of water is stopped by a 5 cm diam. disc of 1.5 mm Paxolin drilled and tapped 2 B.A. centrally.

The disc is attached to the fulcrum piece by a 32 cm length of 4.5 mm dural. rod so that it is vertical and directly below the fulcrum. The ends of this rod are bent and threaded very easily.

The fulcrum piece used is a scrap of 1 cm Ebonite 5 cm long. The fulcrum, which could be improved, is merely a 3 mm diam. hole which slides over a knife edge.

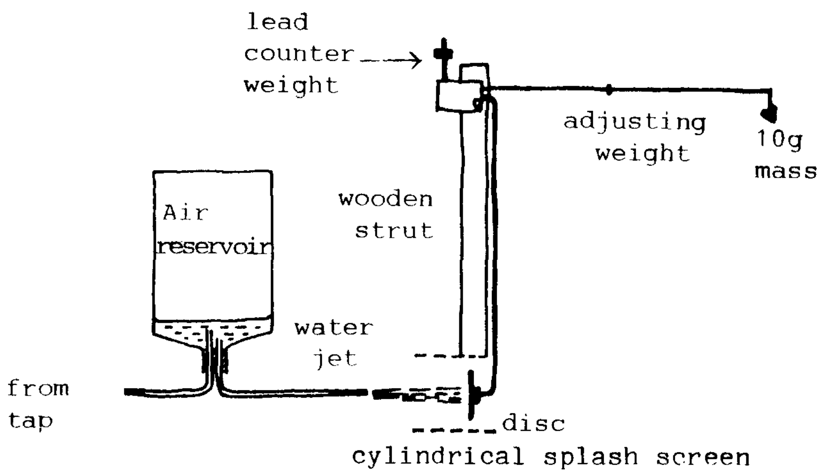


Fig 3.16

The horizontal arm is also 4.5 mm dural. rod. A notch filed in it at the appropriate distance from the fulcrum takes the thread from the 10 g mass.

The lead counterweight is so positioned on a screwed rod that the C.G. is sufficiently close beneath the fulcrum to give the required sensitivity.

A small adjusting weight rides on the horizontal arm. The knife edge protrudes from a vertical wooden strut which is held in a clamp stand. To the lower end of the strut is attached a rectangle of celluloid which is curved right round to form a cylindrical splash screen round the disc. A device limits the movement of the disc to 12.5 mm.

Operation

1. The momentum balance is adjusted until it is swinging freely and comes to rest with the disc at the midpoint of its range of movement. A force of 0.1 g on the disc should cause a noticeable displacement.

2. The 10 g mass on a loop of thread is hung on the groove on the horizontal arm.

3. The water is turned on and adjusted until the jet, striking the centre of the disc, maintains the disc in its original position of equilibrium.

Sample readings and calculation

	Volume of water collected in 10s	= 350 cm^3
	Diameter of water jet tube	= 0.40 cm
hence	Rate of flow	= 35 gs^{-1}
and	Velocity of water jet	= 278 cms^{-1}
therefore	Rate of change of momentum of water	= 35 x 278
		= 9730 c.g.s. units
and	Force exerted on water by plate	= 10 g wt.
		= 0.0981 N

Notes

1. For simplicity the moment arms are made equal and the 10 g mass is kept constant. Thus when equilibrium is regained the force exerted by the water is 10 g wt.

2. Difficulties caused by variation in the water pressure may be diminished by incorporating an air reservoir as shown. The larger the reservoir is the greater is the smoothing.

XVIII. EXPERIMENTAL PROOF OF 'FORCE = d/dt (MASS X VELOCITY)'

J.D. Maclennan

Newton's Second Law is at present proved experimentally by measuring the uniform acceleration produced in a body by a steady force. This results in the expression

force = mass x acceleration

This apparatus was devised in order to prove the Law quantitatively in its original and more fundamental form, and also to give a qualitative demonstration at junior school level of some of the concepts of the kinetic theory of gases.

Four mm glass beads are allowed to fall at a uniform rate through a vertical height h on to a plate inclined at 45 to the horizontal and hung from the arm of a self indicating balance (a Stanton was used in this case)(Figure 3.17).

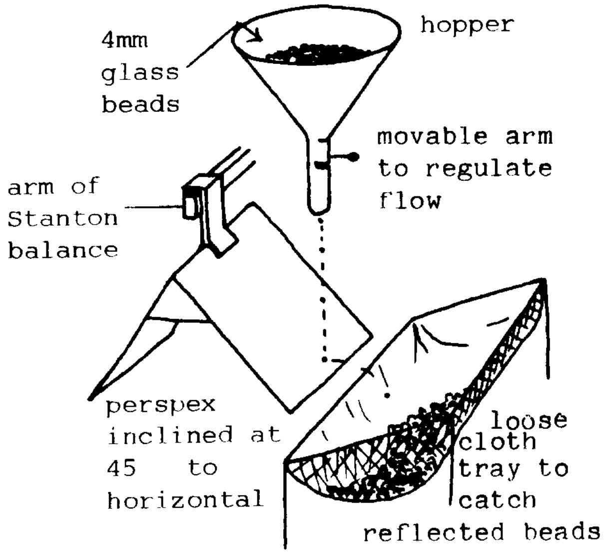


Fig. 3.17

The beads rebound from the plate horizontally, i.e. their vertical momentum at impact has been changed to zero. The velocity at impact is given by the expression

$$v = (2gh)^{1/2}$$

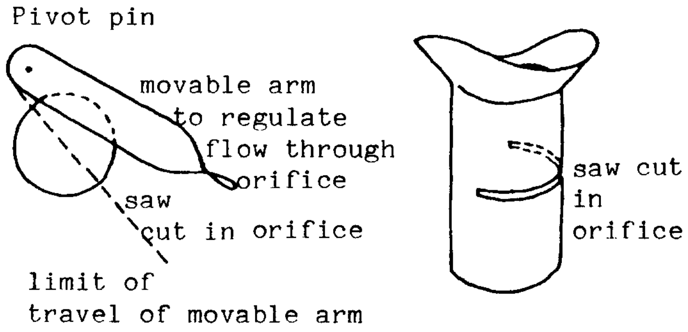
and the rate of change of momentum by

$$(M/T)(2gh)^{1/2}$$

where M is the total mass of beads and T the time in seconds for the beads to fall.

In a typical case, the balance indicates, within 2-3 seconds, a mean reading of, say, 8.4 gf which may vary by ± 0.3 gf during the run. Using 0.5-1 kg of glass beads, the cascade normally lasts between 10 and 20 seconds so that the force is seen to be steady and a mean value readily obtained.

The hopper was constructed of tin plate and the valve controlling the flow was a piece of flat metal hinged at one end on the outside of the orifice and moving in the horizontal plane (Figure 3.18).



A saw-cut half-way through the orifice allowed this valve plate to interrupt the flow of particles to any desired extent. A movable clamp, in this case part of a large spring back paper clip, was used on the outside of the orifice to act as a stop for the valve plate, so that several runs with exactly the same rate of flow can be obtained.

The results recorded in Figure 3.19 were obtained by a fifth-year student and show the degree of correlation between force and change of velocity at impact for a fixed mass per second of 46g. The experimental results are uniformly 14% below the theoretical values, and this is explicable when account is taken of the coefficient of restitution between the glass beads and the Perspex plate.

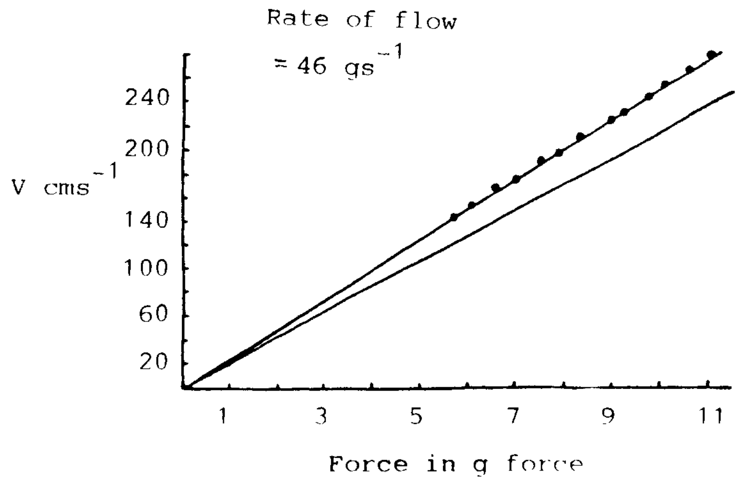


Fig. 3.19

To junior classes this quickly demonstrates that:

1. A number of small impacts constitute a force and

2. This force is increased if

   (a) the velocity

or

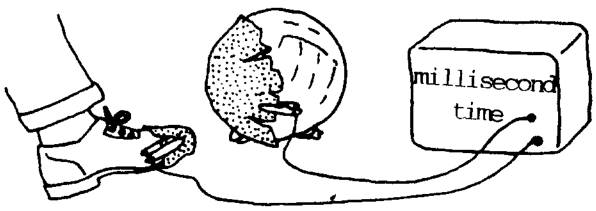
   (b) the number of impacts per second are increased,

thus showing how Charles' and Boyle's laws can be explained using the particle theory of matter.

In practice, the spent beads may be readily scooped out of the cloth tray by a small beaker and transferred to a large beaker for weighing or replenishing the conical hopper.

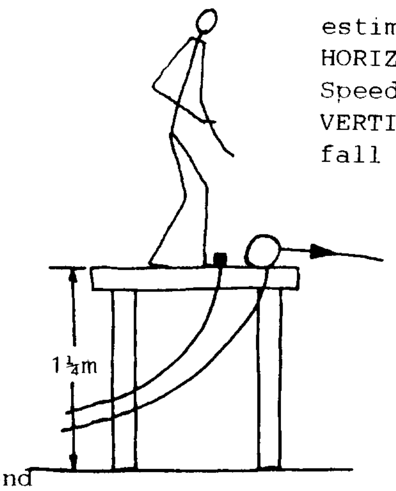
XIX. KICKING A FOOTBALL — Nuffield O-level Year 4

Cover the player's boot with kitchen foil; cover the football with kitchen foil. Then the time-of-contact between boot and ball can be measured with a scaler which counts thousandths of a second.



The ball starts at rest; and to calculate its acceleration you need to know its final speed at the end of a kick. Kick the ball from a table 1.25 metres above the floor. If the ball flies out horizontally it will take 0.5s in its accelerated vertical fall to reach the floor. Measure the distance the ball travels horizontally estimate it took 0.5s to do this, and calculate its speed.* Find the mass of the ball in kilograms by weighing it. Use F = ma to calculate the force.

* Or you might measure the speed by taking a multiflash photo of the flying ball.



XX. MAKE ONE OF THESE ACCELEROMETERS

Project Physics

An accelerometer is a device that measures acceleration. Actually, anything that has mass could be used for an accelerometer. Because you have mass, you were acting as an accelerometer the last time you lurched forward in the seat of a car as the brakes were applied. With a knowledge of Newton's laws and certain information about yourself, anybody who measured how far you leaned forward and how tense your muscles were would get a good idea of the magnitude and direction of the acceleration that you were undergoing; but it would be complicated.

Here are four accelerometers of a much simpler kind. With a little practice, you can learn to read accelerations from them directly, without making any difficult calculations.

A. The Liquid-Surface Accelerometer

This device is a hollow, flat plastic container partly filled with a colored liquid. When it is not being accelerated, the liquid surface is horizontal, as shown by the dotted line in Fig. 3.20. But when it is accelerated toward the left (as shown) with a uniform acceleration **a**, the surface becomes tilted. The level of the liquid rises a distance **h** above its normal position at one end of the accelerometer and falls the same distance at the other end. The greater the acceleration, the more steeply the surface of the liquid is slanted. This means that the slope of the surface is a measure of the magnitude of the acceleration **a**.

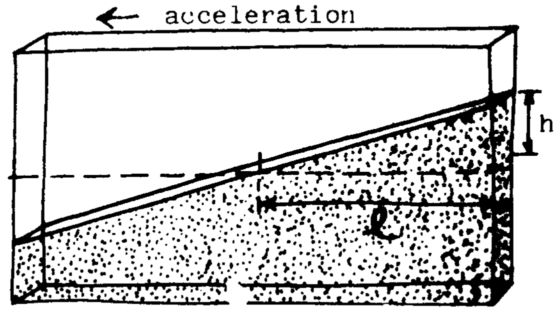
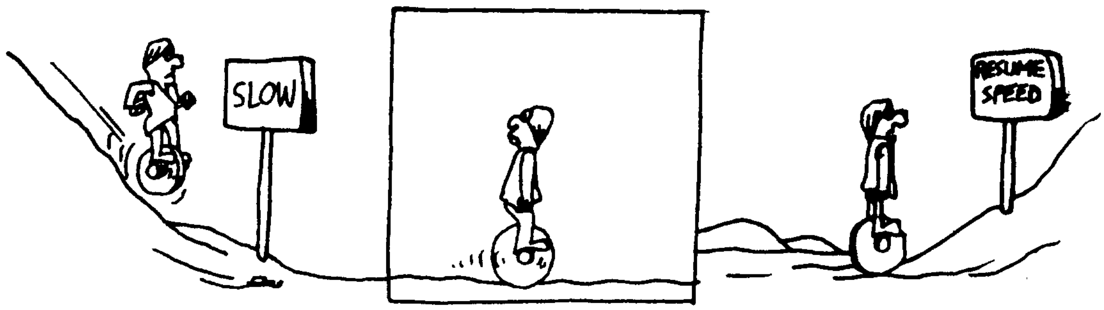


Fig 3.20.

The length of the accelerometer is $2l$, as shown in Figure 3.20. So the slope of the surface may be found by:

$$\text{slope} = \frac{\text{vertical distance}}{\text{horizontal distance}}$$



$$= \frac{2h}{2l}$$

$$= \frac{h}{l}$$

Theory gives you a very simple relationship between this slope and the acceleration **a**:

$$\text{slope} = \frac{h}{l} = \frac{a}{a_g}$$

Notice what this equation tells you. It says that if the instrument is accelerating in the direction shown with just a_g (one common way to say this is that it has a "one-G acceleration" - the acceleration of gravity), then the slope of the surface is just 1; that is, $h = l$ and the surface makes a 45 angle with its normal, horizontal direction. If it is accelerating with $1/2a_g$, then the slope will be 1/2; that is $h = 1/2l$. In the same way, if $h = 1/4l$, then $a = 1/4a_g$, and so on with any acceleration you care to measure.

To measure **h**, stick a piece of centimeter tape on the front surface of the accelerometer as shown in Fig. 3.21. Then stick a piece of white paper or tape to the back of the instrument to make it easier to read the level of the liquid. Solving the equation above for **a** gives:

$$a = a_g \times \frac{h}{l}$$

Since a_g is very close to 9.8 ms^{-2} at the earth's surface, if you place the scale 9.8 scale units from the center, you can read accelerations directly in meters per second^2. For example, if you stick a centimeter tape just 9.8 cm from the center of the liquid surface, 1 cm on the scale is equivalent to an acceleration of 1 ms^{-2}.

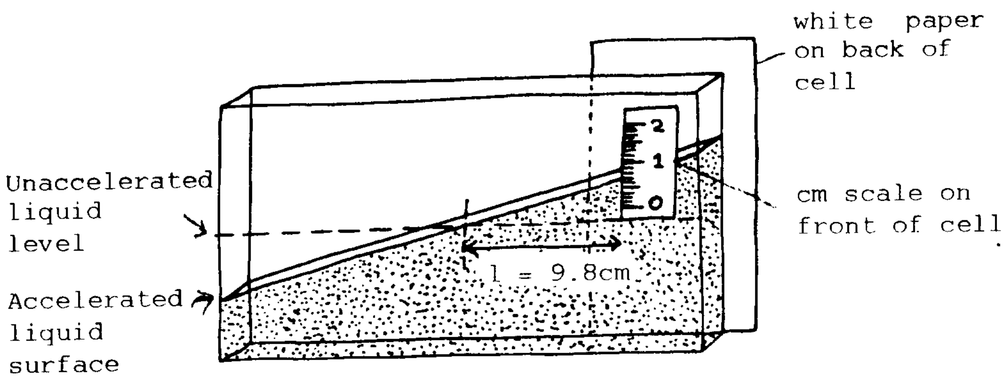


Fig. 3.21

Calibration of the Accelerometer

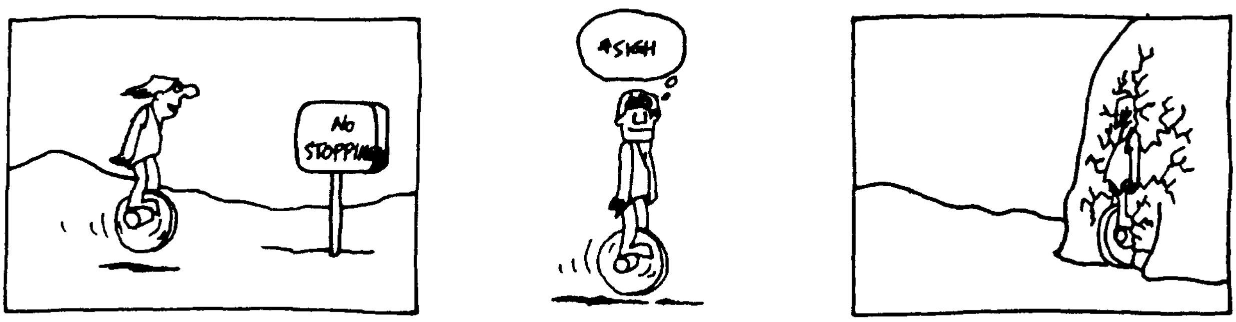
You do not have to trust blindly the theory just mentioned. You can test it for yourself. Does the accelerometer really measure accelerations directly in meters per second^2? Stroboscopic methods give you an independent check on the correctness of the prediction.

Set the accelerometer on a dynamics cart and arrange strings, pulleys, and masses to give the cart a uniform acceleration on a long tabletop. Put a block of wood at the end of the cart's path to stop it. Make sure that the accelerometer is fastened firmly enough so that it will not fly off the cart when it stops suddenly. Make the string as long as you can, so that you use the entire length of the table.

Give the cart a wide range of accelerations by hanging different weights from the string. Use a stroboscope to record each motion. To measure the accelerations from your strobe records, plot **t^2** against **d**. (What relationship did Galileo discover between **d/t^2** and the acceleration?)

Compare your stroboscopic measurements with the readings on the accelerometer during each motion. It takes some cleverness to read the accelerometer accurately, particularly near the end of a high-acceleration run. One way is to have several students along the table observe the reading as the cart goes by; use the average of their reports. If you are using a xenon strobe, of course, the readings on the accelerometer will be visible in the photograph; this is probably the most accurate method.

Plot the accelerometer readings against the stroboscopically measured accelerations. This graph is called **a calibration curve.** If the two methods agree perfectly, the graph will be a straight line through the origin at a 45° angle to each axis. If your curve has some other shape, you can use it to convert "accelerometer readings" to "accelerations" if you are willing to assume that your strobe measurements are more accurate than the accelerometer. (If you are not willing, what can you do?)



B. Automobile Accelerometer I

With a liquid-surface accelerometer mounted on the front-to-back line of a car, you can measure the magnitude of acceleration along its path. Here is a modification of the liquid-surface design that you can build for yourself. Bend a small glass tube (about 30 cm long) into a U-shape, as shown in Figure 3.22.

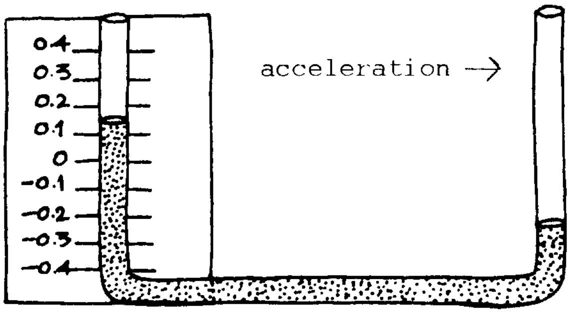


Fig. 3.22

Calibration is easiest if you make the long horizontal section of the tube just 10 cm long; then each 5 mm on a vertical arm represents an acceleration of 0.1 g = (about) 1 ms^{-2}, by the same reasoning as before. The two vertical arms should be at least three-fourths as long as the horizontal arm (to avoid splashing out the liquid during a quick stop). Attach a scale to one of the vertical arms, as shown. Holding the long arm horizontally, pour colored water into the tube until the water level in the arm comes up to the zero mark. How can you be sure the long arm is horizontal?

To mount your accelerometer in a car, fasten the tube with staples (carefully), to a piece of plywood or cardboard a little bigger than the U-tube. To reduce the hazard from broken glass while you do this, cover all but the scale (and the arm by it) with cloth or cardboard, but leave both ends open. It is essential that the accelerometer be horizontal if its readings are to be accurate. When you are measuring acceleration in a car, be sure the road is level. Otherwise, you will be reading the tilt of the car as well as its acceleration. When a car accelerates, in any direction, it tends to tilt on the suspension. This will introduce error in the accelerometer readings. Can you think of a way to avoid this kind of error?

C. Automobile Accelerometer II

An accelerometer that is more directly related to F = ma can be made from a 1 kg cart and a spring scale marked in newtons. The spring scale is attached between a wood frame and the cart as shown in Fig. 3.23. If the frame is kept level, the acceleration of the system can be read directly from the spring scale, since 1N of force on the 1 kg mass indicates an acceleration of 1 ms^{-2}. (Instead of a cart, any 1 kg object can be used on a layer of low-friction plastic beads.)

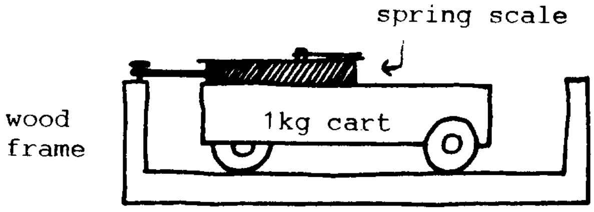


Fig 3.23

D. Damped-Pendulum Accelerometer

One advantage of liquid-surface accelerometers is that it is easy to put a scale on them and read accelerations directly from the instrument. They have a drawback, though; they give only the component of acceleration that is parallel to their horizontal side. If you accelerate one at right angles to its axis, it does not register any acceleration at all. Also, if you do not know the direction of the acceleration, you have to use trial-and- error methods to find it with the accelerometers discussed up to this point.

A damped-pendulum accelerometer, on the other hand, indicates the direction of any horizontal acceleration; it also gives the magnitude, although less directly than the previous instruments do.

Hang a small metal pendulum bob by a short string fastened to the middle of the lid of a 1-litre wide-mouthed jar as shown on the left-hand side of the sketch in Fig. 3.24. Fill the jar with water and screw the lid on tight. For any position of the pendulum, the angle that it makes with the vertical depends upon your position. What would you see, for example, if the bottle were accelerating straight toward you? Away from you? Along a table with you standing at the side? (Careful: This last question is trickier than it looks.)

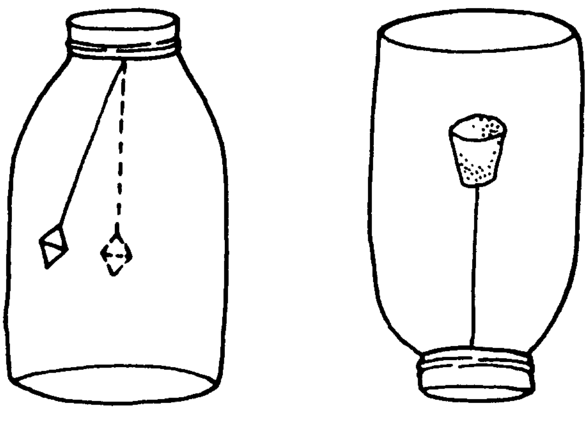


Fig. 3.24

To make a fascinating variation on the damped-pendulum accelerometer, simply replace the pendulum bob with a cork and turn the bottle upside down as shown on the right-hand side of the sketch. If you have punched a hole in the bottle lid to fasten the string, you can prevent leakage with the use of sealing wax, paraffin, or tape.

This accelerometer will do just the opposite from what you would expect. The explanation of this odd behavior is a little beyond the scope of this course; it is thoroughly explained in **The Physics Teacher**, Vol. 2, No. 4 (April, 1964), p. 176.

XXI. H.F.Meiners (Editor)

The accelerated system consists of a box with transparent sides of cellophane mounted on roller skate wheels as shown in Fig. 3.25. A rubber balloon filled with air is suspended from the top of the box and another balloon filled with helium is attached by a string to the bottom of the box. When the system is accelerated, the helium balloon moves in the direction of motion while the air-filled balloon moves in the opposite direction.

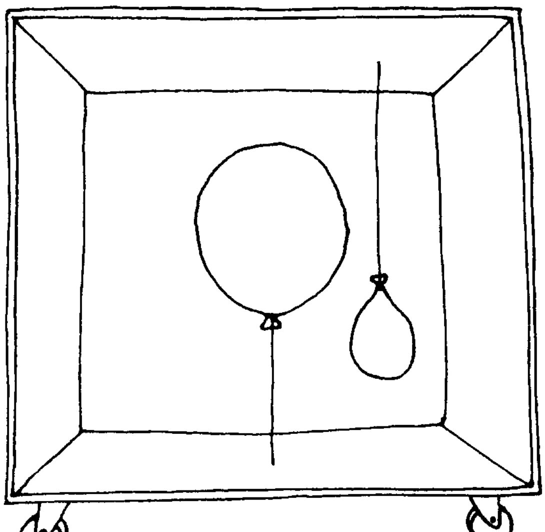


Fig. 3.25

XXII. LIQUID ACCELEROMETERS P.M.Sutton (Editor)

The inertia of a liquid may be utilized in various manometers for measuring linear acceleration, either vertical or horizontal, centripetal acceleration and speed of rotation , or angular acceleration.(1)

In simplest form for the measurement of horizontal acceleration, the manometer consists of a U-tube filled with mercury or water (Figure 3.26a). The inertial reaction due to acceleration of liquid in the horizontal arm of the U is equalized by a difference in pressure in the two vertical arms, so that $h = La/g$, which is independent of the size of tube or density of liquid. The sensitivity of the device depends primarily upon the horizontal length L.

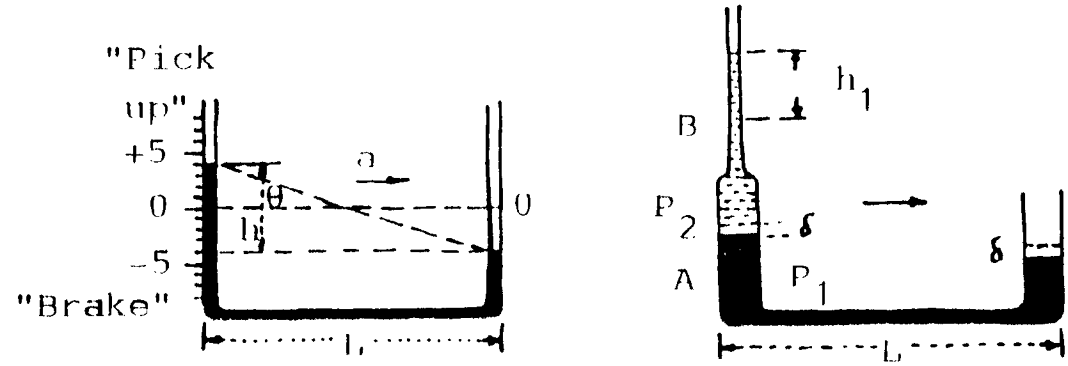


Fig. 3.26. Liquid accelerometers:
(a) simple form; (b) multiplying form.

For lecture purposes, it is desirable to increase the sensitivity of the accelerometer without increasing its length. This may be done by making the manometer as shown in Fig. 3.26b. The horizontal arm is filled with mercury, which extends into the vertical arm a short distance. The area of cross section of one arm is reduced from A to B at some point above the interface between mercury and colored water in that arm. Thus the inertia of the horizontal mercury column is equalized in large part by the change in level of water in the constricted arm of the U. The relation between change in height in this arm alone and the horizontal acceleration is then given by

$$h_1 = \left(\frac{\rho_1 A}{2B\rho_1 + (A - B)\rho_2} \right) \cdot \frac{La}{g}$$

where $_1$ and $_2$ are the densities of the heavy and the light liquids respectively. It will be observed that the relationship between a and Δh_1 is linear and that the instrument may be calibrated linearly along the tube B directly in metres per second per second or other convenient unit, solely from a knowledge of the geometrical and density factors involved.

(1) Sutton, R.M., Am. Phys. Teacher. 3.77., 1935.

XXIII. UNIFORM ACCELERATION, USING LIQUID ACCELEROMETER Project Physics

This demonstration allows you to show that when a cart moves with constant acceleration **a**, the surface of the liquid is a straight line tilted in the direction of the acceleration.

Give the cart a uniform acceleration by suspending an object over a pulley, as in Figure 3.27. It is best to use objects whose masses range from 100 to 400 g. It is important to keep the string as long as possible, so that you use the entire length of the table. By changing the mass of the suspended object, you can vary the acceleration of the cart. Notice that the slope of the liquid increases with greater acceleration. The slope is thus a measure of the acceleration. It can be shown that

$$\tan \theta = a/g$$

so that $a = g \tan \theta$.

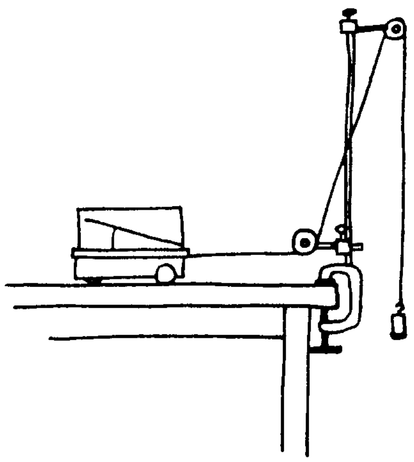


Fig. 3.27 Arrangement to demonstrate uniform acceleration

XXIV. DIRECTION OF ACCELERATION AND VELOCITY Project Physics

Using the same arrangement as in XXIII, this is a demonstration showing that acceleration and velocity can have different directions.

Hang an object of 100 and 200 g mass over a pulley and give the cart a push to the left so that it goes nearly to the end of the table before it stops and reverses direction. You should try to give a short, smooth push so that the liquid reaches its steady state quickly. Once the water has reached its steady state, the surface is a straight line whose slope does not change, even when the velocity reverses direction. The explanation, of course, is that the acceleration is constant and independent of the velocity. Only the weight of the object over the pulley determines the acceleration of the cart.

XXV. NEWTON'S-LAW EXPERIMENT (AIR TRACK) Project Physics

With the calibrated accelerometer you can perform experiments to define forces in terms of the accelerations of objects whose masses are known. The accelerometer would enable you to determine the accelerations directly.

XXVI. UNIFORM CIRCULAR MOTION Project Physics

To demonstrate the acceleration in uniform circular motion, place the accelerometer along the diameter of a phonograph turntable. When the turntable rotates, the liquid surface is parabolic. Figure 3.28 shows this situation. The acceleration increases with the distance from the center and is always directed inward. By changing the speed of the turntable, you can show that the acceleration is greater for higher speeds of rotation.

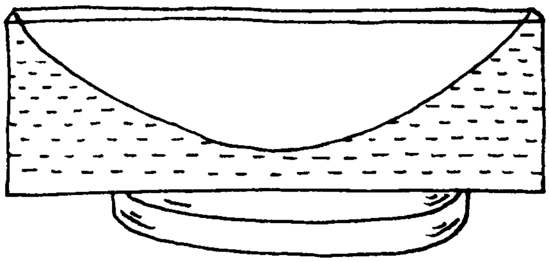


Fig. 3.28

XXVII. SPEED OF ROTATION BY MANOMETER P.M.Sutton (Editor)

A U-shaped manometer containing water or mercury is mounted with one of its arms coincident with the axis of a rotating table. The necessary centripetal force on the liquid in the horizontal tube is introduced by the difference in level in the two arms, a quantity that is easily observed by the fall of liquid in the axial arm of the U. The depression in level of the liquid in the axial arm of the U is $\Delta h = \omega^2 r^2/4g$, where r is the length of the base of the U, and is the angular speed in radians per second. It will be observed that Δh is independent of the density of the liquid filling the manometer.

XXVIII. H.F. Meiners (Editor)

A lighted candle in a glass chimney placed within a large closed container (Figure 3.29) will continue to burn for a considerable time because of convection. But the flame will be extinguished when the system is dropped. The flame will not receive oxygen during free fall because circulation of the oxygen depends on both a density and pressure gradient. The gravitational pressure gradient becomes zero in free fall, and when all the oxygen near the candle is gone, the candle dies. Oxygen is still within the system, but it cannot get to the candle.

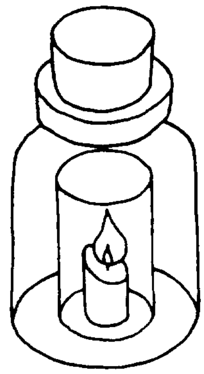


Fig. 3.29

Adapted (words) and redrawn (illustrations) from: **University Physics, Experiment and Theory**, by George D. Freier. Copyright (1965) by Meredith Publishing Company.

XXIX. H.F. Meiners (Editor)

A Lucite box containing colored glycerine is mounted on a cart that runs with little friction down inclined rails. When the car is released and allowed to accelerate down the incline, the free surface of the liquid sets itself parallel to the incline. The liquid surface maintains that slope as long as the cart is accelerating. If the cart is given a push from the bottom of the hill and allowed to run uphill, decelerating, the liquid surface remains parallel to the incline, even at the highest point where the cart is momentarily at rest but still decelerating. If the cart is held at rest, as shown in Figure 3.30, the liquid surface will be parallel to the horizontal.

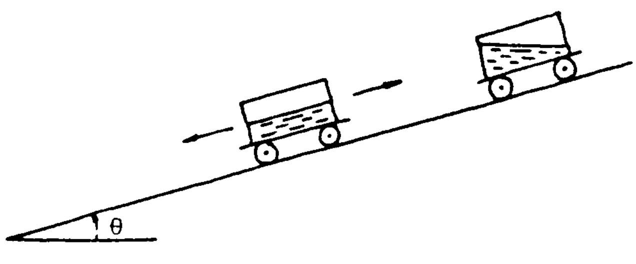


Fig. 3.30.

XXX. a) ACCELEROMETERS J.C. Siddons
(- - - -)

If a spirit level (Figure 3.31) held really level has a horizontal acceleration **a** then the air bubble will move forward to the position it would be at if the level were tilted at an angle of $\tan^{-1}$ **a/g**. Alternatively if the spirit level is tilted forward as B and C are in Figure

3.31 and if the angle of tilt is exactly $\tan^{-1}$ **a/g** then the bubble will be exactly central, that is, the tilted level will appear horizontal.

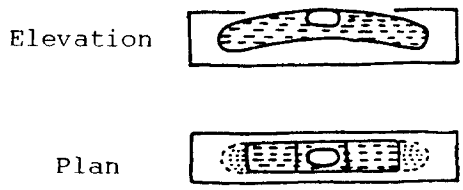


Fig. 3.31

To calibrate such a spirit level accelerometer measure the deflection from the central position of the air bubble when the level is placed at various slopes. (Either the centre of the bubble can be used or one of its ends.) Suppose, for example, that a slope of 1 in 50 will just move the bubble to the outside of the marked line on that side (Figure 3.32). Then an acceleration of **g**/50 will also move the bubble to this position.

Fig. 3.32

A single ordinary spirit level can only be used if the acceleration is very small (**g**/50). Small spirit levels can be bought quite cheaply; if three are mounted at different angles on a base as shown in Fig. 3.32 the range of measurable accelerations can be greatly increased. The tilts should be arranged so that when the A bubble goes out of sight the B bubble just comes into play. The addition of other lines to the two normally present either by cutting on the glass or the use of a thin piece or sticky paper facilitates measurement.

I have used a mount of two such spirit levels to study the acceleration of diesel trains (it will fit quite unobtrusively in the window-sill). The slope, if any, of the railway line must be known and it must be allowed for; this is very easy, being simply an addition or subtraction. As was to be expected the trains start off with a bigger acceleration than they maintain, but accelerations of 0.01**g** can be noticed even after a minute or more.

Through the good offices of Mr. J.W. Cottingham I obtained a long curved glass tube with which I made a long open spirit level. (At first

I used water to fill the tube but had to change to spirit as the air bubble in water often splits up and will not reform.) This spirit level will measure the angle of tilt produced by the acceleration of a trolley-bus - about 10 corresponding to an acceleration of **g**/6. Mounted as shown in Figure 3.33 and pulled by a weight (hanging over a pulley) which hits the ground after which the trolley continues with almost constant velocity, the spirit level shows very clearly the difference between accelerated and constant velocity.

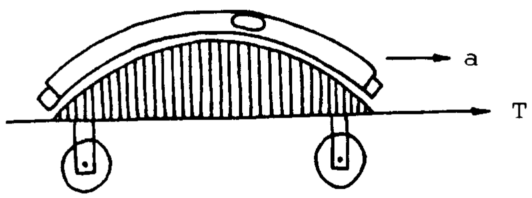


Fig. 3.33

b) ACCELERATION TOPPLER

The Kelly, the toy that when knocked over always rights itself, is well-known and popular in centre of gravity lessons. A variation of it can be used as an acceleration indicator. Fix a sheet of cardboard in a slot in a wooden hemicylinder as shown in Fig. 3.34. The centre of gravity of the body should be only slightly below the axial line of the cylinder (denoted by the distance **x** in Figure 3.35). On being pushed over on to its side it should right itself. Put the toppler on a trolley (I find that it is more reliable if it rests on model railway lines than if it rests on wood). Make the trolley accelerate. Let its acceleration be **a**. Then if **a**/**g** > **x**/r the toppler will topple over and stay put. If the acceleration is less than this the toppler tilts and oscillates.

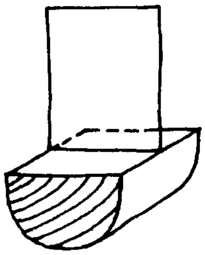


Fig. 3.34

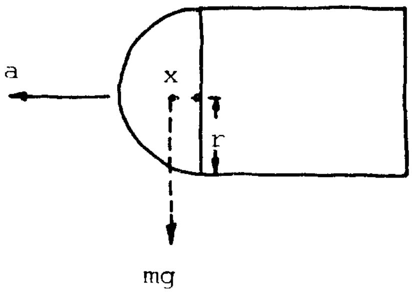


Fig. 3.35

Arrange the run of the trolley on the bench in two parts, the first to be accelerated, the second to be retarded (it can run on to cloth or it can collide with a block of wood which it then pushes). With the change from acceleration to retardation the toppler gets up from its lying backwards position only to fall forwards.

If the toppler is placed near the outside of a turn-table which is then slowly rotated it will fall outwards. If the rotation is too great it will skid outwards as well. Reverse the direction of rotation. It will still topple outwards, showing that the acceleration is towards the centre whichever way the rotation.

XXXI. FLETCHER'S TROLLEY - ALIVE AND WELL

D. Easton

In spite of the usurpation of its favored position in high school labs by the linear air track with its low, low friction, Fletcher's trolley may be used with considerable success in an analysis of Newton's second law. In fact, the much greater friction of the trolley can be extremely advantageous in weakening senior physics students' "intuitive" --in the Aristotelian sense--notions that force and velocity are somehow related.

The trolley that I use has been modified by the addition of a carpenter's spirit level that serves as an accelerometer. I install the trolley at the front of the classroom and ask students to "play" with it and to prepare answers for these questions.

1. What happens to the bubble when the trolley is pushed?

2. What happens if the trolley is given a harder push?

3. What happens when the trolley moves at constant speed?

4. What happens to the bubble when the moving trolley is suddenly stopped?

5. What does the position of the bubble indicate?

Students are quickly satisfied that the bubble moves in response to accelerations of the trolley and that the bubble always moves in the direction of the acceleration. A push from the rear of the trolley causes the bubble to shoot forward, indicative of a forward acceleration; whereas, stopping the moving trolley causes the bubble to suddenly shift to the rear, indicating a rearward acceleration. When the trolley moves at constant speed, the bubble rests in its centered position.

As well as indicating the direction of the acceleration, the displacement of the bubble from its central position is a moderately reliable indicator of the relative magnitudes of the trolley's accelerations. A gentle push on the rear of the trolley causes a slight forward shift of the bubble (Figure 3.36), but the much higher acceleration of the trolley, when it stops at the end of its track, causes a very large displacement of the bubble (Figure 3.37).

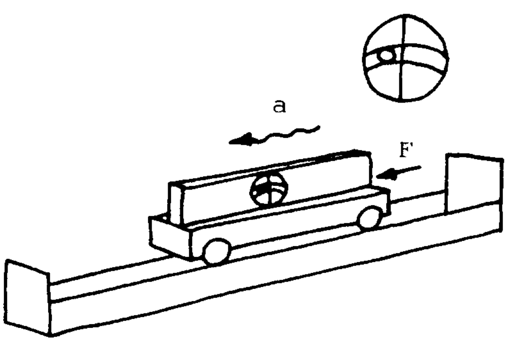


Fig. 3.36

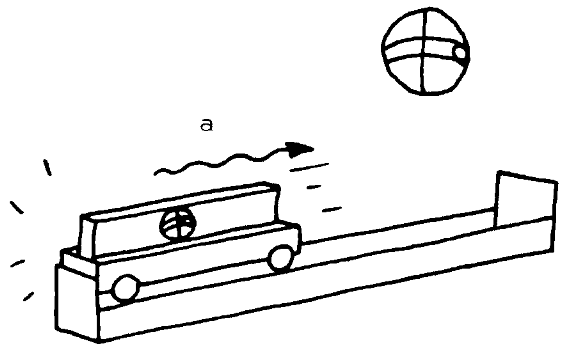


Fig. 3.37

To impress upon students that force and acceleration, but not velocity, are the dynamical variables that belong together, I accelerate the trolley by means of a small weight that is connected to the trolley by a length of string and suspended from a pulley (Figure 3.38). When I release the trolley, the bubble shifts from its centered position toward the front of the trolley in response to its acceleration. The bubble's position - this is easily monitored if the speed of the trolley is kept to small values - remains unchanged until either the weight hits the floor or the trolley reaches the end of its track.

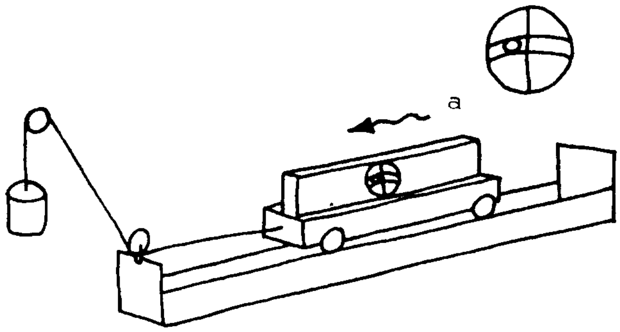


Fig. 3.38. The trolley's acceleration, under the action of the tension in the string, is indicated by the position of the bubble.

This indication of the uniform acceleration of an object experiencing a constant force does not surprise students, but almost certainly the visual impact of the bubble remaining "fixed" as the trolley accelerates will strengthen their association of force and acceleration, while undermining their desire to relate force and velocity.

To deal some further blows to Aristotelian physics, I engage students in a discussion of what will happen if I give the trolley a push to start it moving against the weight so that the trolley goes "up" the track, stops and coasts back "down". I ask the students to predict the bubble's position at every instant during the trolley's motion. After the inevitable arguments and disagreement the matter is put to the test.

I knew, or thought I knew, that the bubble would necessarily shift in the direction of the string's tension and stay shifted throughout the entire motion, yet it afforded me no small pleasure to watch for the first time the bubble "faithfully" indicating the acceleration of the trolley even as it slowed and instantaneously stopped before returning "down" the track.

When I am convinced that students recognize that the bubble, as an indicator of acceleration, must be displaced while there is tension in the string, regardless of the instantaneous motion of the trolley; I ask them to consider forces, **other than the tension in the string,** that influence the acceleration of the trolley. After some discussion it is agreed that the only force with a magnitude comparable to the tension in the string is the force of friction acting on the trolley. Students have a fairly well developed friction sense and are able to argue qualitatively what will be the effects of friction.

Since friction acts at all times to retard the motion of the trolley, the direction of the force of friction must change at the instant the trolley changes direction. When the trolley is going "up" the track, the force of friction opposing its motion is in the same direction as the tension in the string. When the trolley comes back "down" the track, the force of friction still opposes its motion, but now the frictional force is directed in the opposite sense to the tension in the string. Hence, the acceleration of the trolley is greater when it goes "up" the track than when it returns (Figure 3.39).

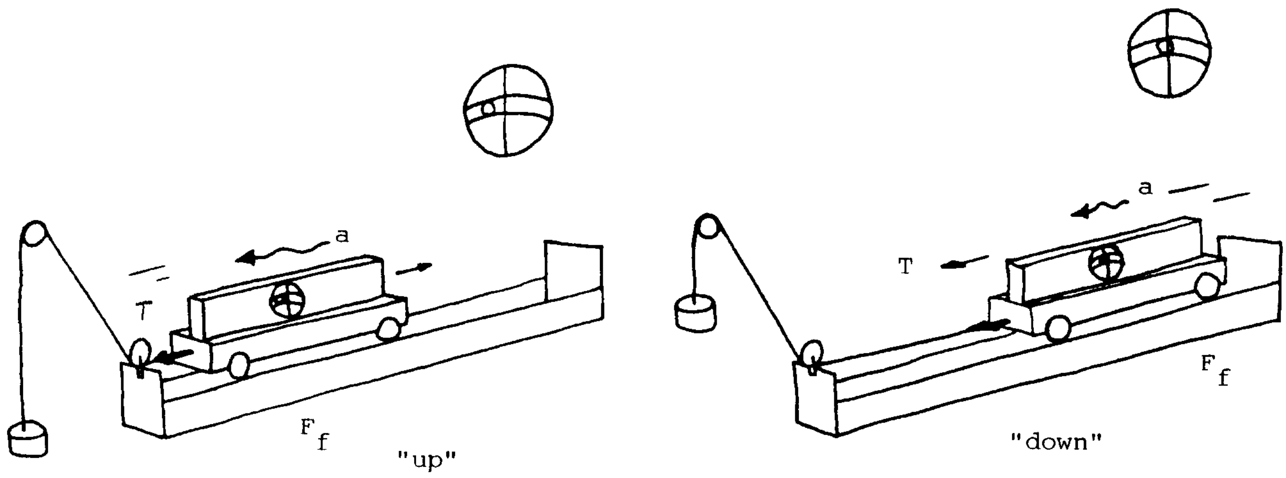


Fig. 3.39. The forces acting on the trolley as it goes "up" the track are different from the forces when it returns.

The conclusion arising from this quasi-free-body analysis is nicely borne out by the bubble accelerometer. Although the bubble at each instant indicates an acceleration in the direction of the tension in the string, it does not show a constant acceleration. At the instant the trolley changes direction the bubble noticeably shifts toward its centered position, in response to what must be a reduction in the acceleration of the trolley. Some students will have seen this shift of the bubble already. For those who have not, I repeat the experiment.

XXXII. ACCELERATION IN LINEAR AND CIRCULAR MOTION

S.H. Kellington and W. Docherty

At some point in the study of acceleration in linear and circular motion, the effect on a person experiencing such accelerations is discussed. This often creates difficulties for pupils because everyday descriptions of such effects seem to conflict with the explanations offered by the physics teacher. A typical example is the effect on a standing passenger in a bus when it suddenly decelerates. The everyday description would be that the passenger is 'thrown forwards' but the physics teacher would probably refer to the first law of motion and explain that the passenger is really continuing in a state of uniform motion whilst the bus is decelerating. The description of the motion of a passenger in a motor car which is negotiating a bend often causes greater confusion.

In attempting to clarify points such as those above, it has been found extremely useful to employ a simple accelerometer in the form of a standing passenger. The device can be used to indicate acceleration and, with careful construction, to make measurements. Figure 3.40 shows two models.

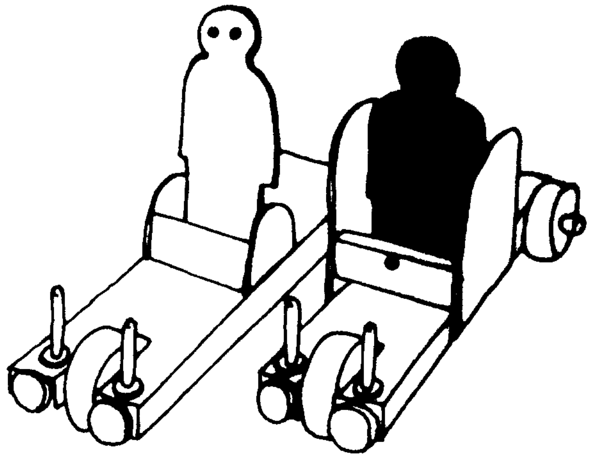


Fig. 3.40. Two designs of the accelerometer

The model man in the one on the left is made very simply from thin plywood and is pivoted through a hole on a horizontal darning needle and suspended on a square frame. Pieces of foam rubber on either side of the feet keep him vertical when stationary and return him to the vertical position after motion. In the model on the right, black perspex has been used and the man is pivoted on two horizontal nylon bolts with tapered ends. Button magnets are used to keep him in a vertical position. Two magnets are screwed to the feet and two similar magnets are held on adjusting screws in the square frame. The adjusting magnets have their poles 'opposing' the respective magnets on the model man. The sensitivity of this model can be increased by moving the adjusting magnets away from the man. Two other methods of increasing sensitivity are to increase the weight of the head of the man with plasticine, and to lower the pivot. A circular scale has been fitted so that the nylon bolts pass through its centre.

A suggested series of demonstrations with the perspex model is as follows.

LINEAR MOTION

1. Acceleration, deceleration and constant speed

Mount the model on a mechanics trolley, or on another vehicle which can move only in a straight line, so that the man is facing in the direction of the subsequent motion. Push the trolley quickly, then allow it to move at constant speed and finally make it decelerate quickly to rest.

Conclude, as in Figure 3.41, that under acceleration and deceleration the man leans backwards and forwards respectively, and mark the scale on either side of the vertical line to indicate this, possibly with positive and negative signs as in Figure 3.39. Point out that at constant speed he remains vertical and explain this result in terms of the first law of motion. Relate the behaviour of the man to pupils' experiences in vehicles.

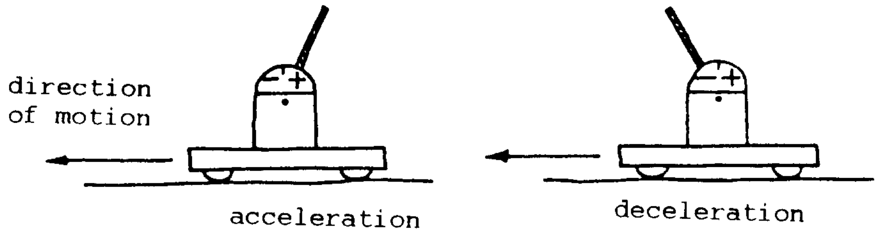


Fig 3.41 Acceleration and deceleration

2. Measurement of acceleration

Using the above arrangement, show that the man leans backwards at larger angles as the acceleration increases. A good model will allow the scale to be marked in terms of the magnitude of the acceleration. The usual elastic strings could be employed and the scale marked in terms of the number of strings in use. Preliminary measurements of acceleration using the accelerometer would be a good introduction to a sequence of measurements using ticker tape and could establish a relationship between force and acceleration. Pupils of lower ability could avoid the use of ticker tape entirely and yet still make measurements.

3. Inclined plane

(a) Acceleration as a function of the angle of inclination. Place the vehicle on an inclined plane so that the model man faces down the slope and move the adjustable magnets in conjunction so that he is at the zero position of the scale and, hence, perpendicular to the base (see Figure 3.42).

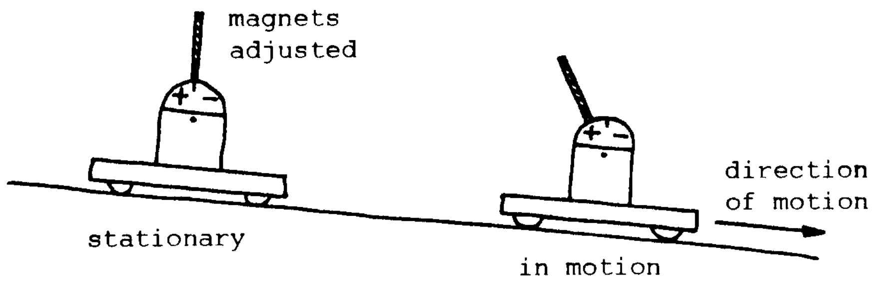


Fig. 3.42. Acceleration on an inclined plane, see 3(a)

Note the angle of the man as the vehicle accelerates down the plane. Point out that the angle remains steady throughout the motion, indicating uniform acceleration. Increase the angle of inclination, adjust the man as before and note the new angle as the vehicle accelerates down the plane. Conclude that the acceleration of the vehicle down a plane is uniform and that it increases as the angle of inclination increases. Use only small angles at this stage.

(b) Diluted gravity and calibration - a more advanced demonstration. Place the vehicle on a horizontal surface and adjust the model man to the vertical position. Allow the vehicle to accelerate down an inclined plane for several increasing angles of inclination, with the man facing down the slope as in part (a). Point out that as the angle of inclination increases, the man, while stationary, leans forward at increasing angles as indicated in Figure 3.43.

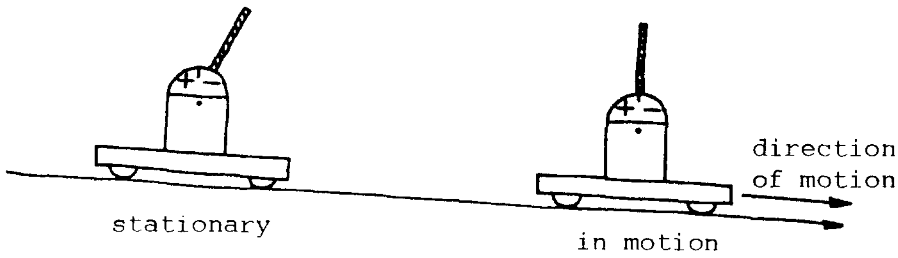


Fig. 3.43. Acceleration on an inclined plane, see 3(b)

Also indicate that, whatever the angle of the plane, the man is perpendicular to the base during the motion of the vehicle. Finally, lift up the vehicle, hold it vertically and carefully allow it to fall freely under gravity. (It is preferable to ask a second person to catch the vehicle.) Note that the model man assumes a horizontal position and is perpendicular to the base as during motion on the inclined plane. Depending on the construction of the man, air resistance may cause him to move slightly beyond the zero position during motion. Explain that as the base of the model is inclined at increasing angles, the component of the gravitational force acting down the plane increases, so increasing the angle at which the man leans forwards. (An alternative explanation could be in terms of the couple acting on the man.) However, it is precisely this component of the gravitational force which produces acceleration of the vehicle. Consequently, during motion down the plane, the man is returned to his 'zero' position. This conclusion, which involves the second law of motion, is very useful because it allows the model to be calibrated very easily as indicated in Figure 3.44.

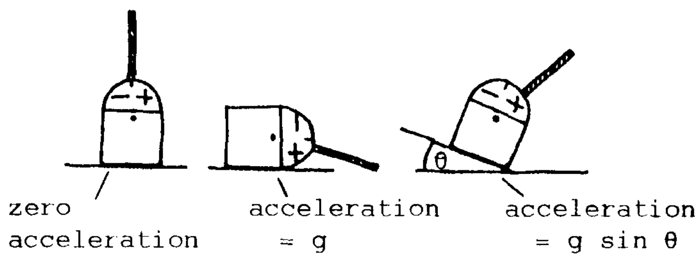


Fig. 3.44. Calibration of accelerometer

If the base is turned to a vertical position, the angle of the man indicates an acceleration of **g**. If the base is at an angle of 0 to the horizontal, the angle of the man indicates an acceleration of **g** sin0.

CIRCULAR MOTION

1. Angular acceleration

Mount the model at the edge of a turntable as shown in Fig. 3.45 so that the model man faces along a tangent in the direction of the subsequent motion.

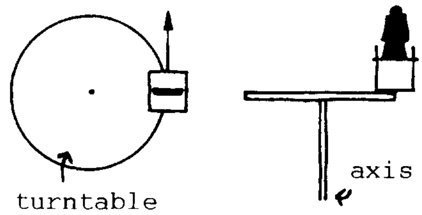


Fig. 3.45. Measurement of angular acceleration

Rotate the turntable by hand and show that he leans backwards during angular acceleration, remains vertical during a constant angular velocity and leans forwards during angular deceleration. A demonstration of the relationship between the angle of the man and the angular acceleration can be given, but unless the axis of the model is carefully aligned along a radius of the turntable, the angle of the man will be affected by the radial acceleration.

2. Radial acceleration

Mount the model as in the previous demonstration but arrange the man to face the centre of the turntable as in Figure 3.46.

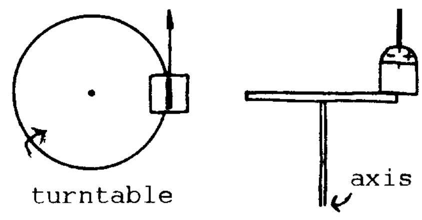


Fig. 3.46. Measurement of radial acceleration

Rotate the turntable and show that the man leans backwards indicating an acceleration towards the centre of the turntable. The acceleration is seen to increase with angular velocity and can be measured if the model has been calibrated. Show that the radial acceleration is present even when the turntable has constant angular velocity. It is worthwhile indicating the relevance of the first law of motion to the behaviour of the man. At the start of the circular motion, his head will tend to move in a straight line along a tangent until the magnets, moving in a circular path, provide a sufficient force to move the man in a circular path. This provides a good starting point for a discussion of centripetal force.

SIMPLE HARMONIC MOTION

The model can be used to show the variation of acceleration with position during simple harmonic motion. The simplest arrangement is probably the simple pendulum, but if the model man is suspended from a single axis point and faces in the direction of the motion, he will not move from the zero position on the scale. The effect of acceleration and deceleration on the man is balanced by the change in the component of the gravitational force acting along the base as the angle between the box and horizontal changes. To observe the variation in the horizontal component of the acceleration, place the model on a piece of wood 30 cm long and 10 cm wide so that the man faces in the direction of the greatest dimension as indicated in Figure 3.47. Suspend both ends of the wood with two parallel strings approximately 1 m in length.

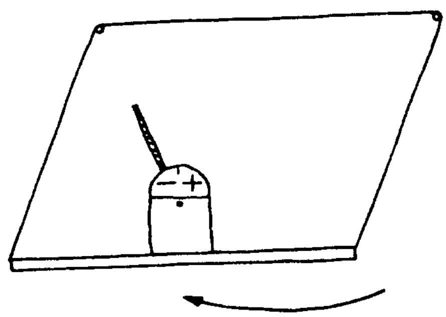


Fig. 3.47. The horizontal component of acceleration during simple harmonic motion

When set in motion of small amplitude in the direction in which the man faces, the wood will stay horizontal. The man is vertical when the wood passes through the lowest position showing zero acceleration. He indicates acceleration when moving from the highest position and deceleration as he moves towards the highest position.

CONCLUSION

The demonstrations suggested above illustrate some of the uses of an accelerometer in school physics and show that some everyday experiences of pupils can be used to introduce concepts in physics instead of appearing to conflict with theories of force and motion.

ACKNOWLEDGEMENTS

The authors wish to acknowledge helpful discussion with their colleagues R. A. Sparkes and J. Boyle.

XXXIII. AN ACCURATE DIRECT READING ACCELEROMETER

Peter W. Hewson, Sabine Jaunich, and Malcolm H. Moreton

Direct measurement of acceleration is a desirable goal because of the fundamental importance of this concept in mechanics. Measurements of accelerations are generally made indirectly from kinematic considerations following on measurements of distance and time. Such calculations are, of course, crucial in understanding the kinematic aspects of acceleration, but become something of a tedious hindrance in studying dynamical relationships.

There are, of course, many situations in which a dynamical analysis leads to a simple direct relationship between acceleration and some other measurable quantity, and some of these have been used to produce workable accelerometers. Kutliroff's filmloop, "Circular Motion" (1) admirably shows the operation and use of a floating cork accelerometer. Wide use is also made of liquid level accelerometers to investigate both direction and magnitude of acceleration in different systems (2- 4) and such liquid level accelerometers are commercially available.

A pendulum mounted on the accelerating system is another simple device that can be used to indicate when acceleration is occurring, and as such has appeared in many a test question, where the practical difficulties of measuring its angular deviation from the vertical can conveniently be ignored. These practical problems were, however, tackled in an investigation of the feasibility of such a pendulum accelerometer, set as an experimental project for students in a second-year physics course. As reported below, this investigation showed that it was possible to make accurate measurements of acceleration up to 0.1g using apparatus which, in the main, is generally available in physics teaching laboratories.

Theory

Consider a compound pendulum of mass **m**, as in Fig. 3.48, whose center of mass, M, is located a distance l from the frictionless support, S. The pendulum and its support are accelerating horizontally with acceleration **a**, with the indicated forces acting on the pendulum, assuming that the center of gravity coincides with the center of mass. The pendulum is in rotational equilibrium.

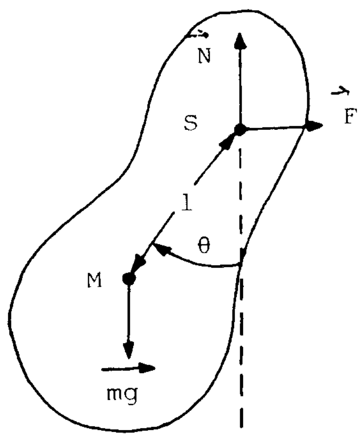


Figure 3.48. Diagram shows forces acting on accelerating compound pendulum.

Translation components:

$$N - mg = 0 \qquad (1)$$
$$F = ma \qquad (2)$$

Rotation components about M

$$0 = F \cdot l\cos\theta - N \cdot l\sin\theta \qquad (3)$$

From (1), (2) and (3)

$$\frac{F}{N} = \frac{a}{g} = \tan\theta$$

$$a = g\tan\theta \qquad (4)$$

This result applies universally since it is independent of the particular properties of the pendulum.

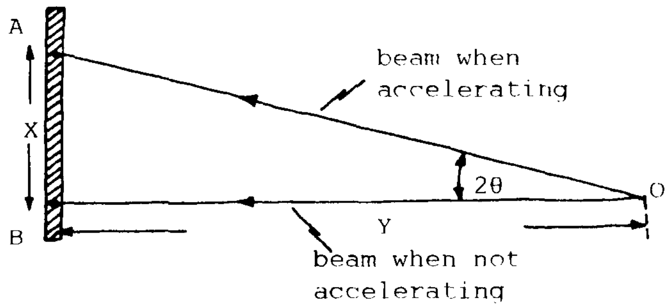


Fig.3.49. Diagrams shows how angle θ is measured

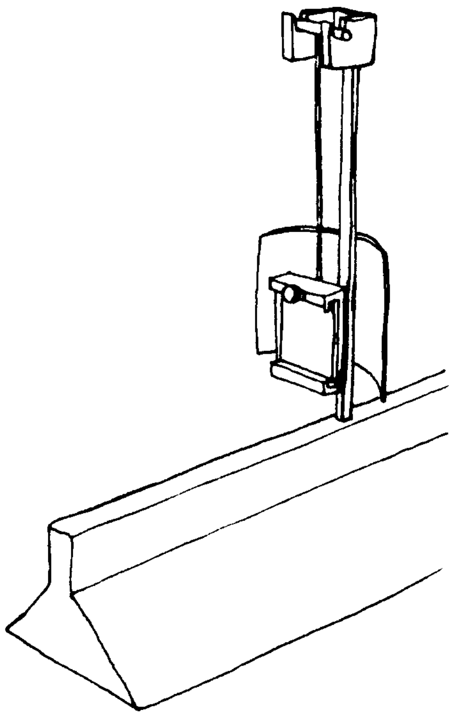
In our experiment angle θ was measured using an optical lever, as shown in Figure 3.49. When the object is not accelerating the beam reflected by a mirror on the pendulum strikes a vertical scale at B. When it is accelerating, the beam strikes the scale at A, and angle BOA = 2θ. Provided that the angles are small and the light falls normally on the screen

$$\tan\theta \simeq \theta \simeq \frac{x}{2y} \qquad (5)$$

Substituting in Eq. (4), we get

$$a \simeq g.\frac{x}{2y} \qquad (6)$$

i.e. for a given value of y, a is directly proportional to the displacement, x, of the spot on the screen.



3.50. The pendulum accelerometer mounted on an airtrack glider.

Experimental Details

The only specially constructed piece of apparatus was the pendulum shown in Figure 3.50 mounted on an airtrack glider. The important features of the design include the mirror, used to measure the angle the pendulum makes with the vertical, screws for adjusting the mirror and thus the horizontal and vertical positions of the reflected light beam and the pendulum hinge. In order to constrain the pendulum to swing accurately in one vertical plane, two support points are necessary. This was achieved by joining the pendulum at right angles to a horizontal axle, the ends of which fitted into grooves on top of the support. The axle's circular cross-sectional shape and size matched that of the grooves. The degree of damping provided by the friction in the support was controlled when necessary by placing one or more layers of paper between groove and axle.

It was also necessary to shield the pendulum from wind resistance. Preliminary results showed a slight tendency for the pendulum to stabilize at too large an angle, but this tendency disappeared when the shield was used.

The light beam was provided by a laser directed parallel to the airtrack, which can be accurately aligned so that the laser beam falls on the same spot on the mirror regardless of where the glider is on the air track. The position of the reflected beam is measured on a vertical scale mounted behind the laser.

The glider was accelerated by means of a falling mass, attached to the glider by a string which passed over a pulley at the end of the air track. As the glider accelerates along the airtrack the spot on the scale at first oscillates. With the pendulum critically damped the oscillations quickly subside and the spot moves slowly up the scale. When the falling mass hits the floor, the acceleration goes to zero, and the spot on the scale immediately drops down. It is thus easy to record the largest displacement, x. The distance, y, is determined from the position of the glider when the mass hits the ground.

A more accurate, though more involved, experimental setup entails the gathering of the reflected beam by a converging lens placed at its focal distance from the scale. Since the movement of the beam does not change its direction, the image formed is stationary, being always at the principal focus of the lens, ensuring that its position can be determined more accurately. The scale is clamped behind the lens in its focal plane and, provided that the principal axis of the lens/scale assembly does not change direction, the assembly can be moved up and down so that for any given acceleration the reflected light falls on the lens. The distance, y will now be the focal length of the lens. The distance, x, will still be the displacement of the spot on the screen even though the screen will have moved, having been fixed in relation to the lens. Even though the magnitude of x will be much less than in the previous setup, it will be much more accurately known. The longer the focal length of the lens, the more accurate the measurement will be.

The accelerations a_d measured dynamically in this way were compared with those calculated kinematically from measurements of distance and time. The glider was always started from the same point. It covered a distance s_0, and the time taken, t, to cover a further distance, s, was then measured. From kinematic considerations it can be shown that the acceleration, assumed constant, is given by

$$a_k = \frac{2(s + 2s_0) - 4\sqrt{s_0(s + s_0)}}{t^2} \qquad (7)$$

In order to check the assumption of constant acceleration, the acceleration was measured for a number of different values of s and s_0. The results showed that the assumption is a very good one.

Results

For a given accelerating mass, both kinematic and dynamic accelerations were measured. It was possible to measure the kinematic acceleration, a_k, to an accuracy of about 1%. The distances s and s_0, used in Eq. (7) to determine a_k, were 42.6 cm and 47.7 cm respectively, and a millisecond timer was used to measure the time, t. The major inaccuracy was the measurement of the displacement, x, of the spot on the scale, leading to an accuracy which was about 10% for small displacements, but dropped to 3% for larger displacements. A lens of focal length 30.9 was used. If lengthened, the accuracy of measurements of a_d would improve.

The accuracy of the measurements of a_k is confirmed by Figure 3.51 which shows that a_k is directly proportional to the accelerating mass. The maximum acceleration which could be reliably determined using the pendulum accelerometer was limited by the length of time for the pendulum to stabilize at the new angle. In Figure 3.52 a_d is plotted against a_k.

As can be seen the agreement between the two different measurements of acceleration is very good over most of the range.

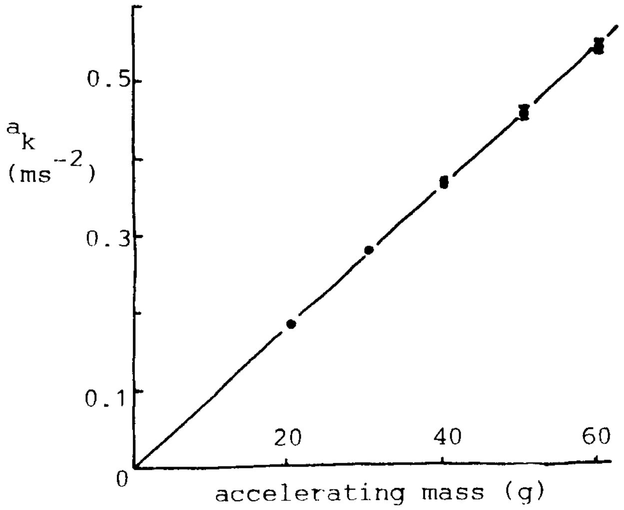


Fig. 3.51. Graph shows how the kinematic acceleration varies with accelerating mass.

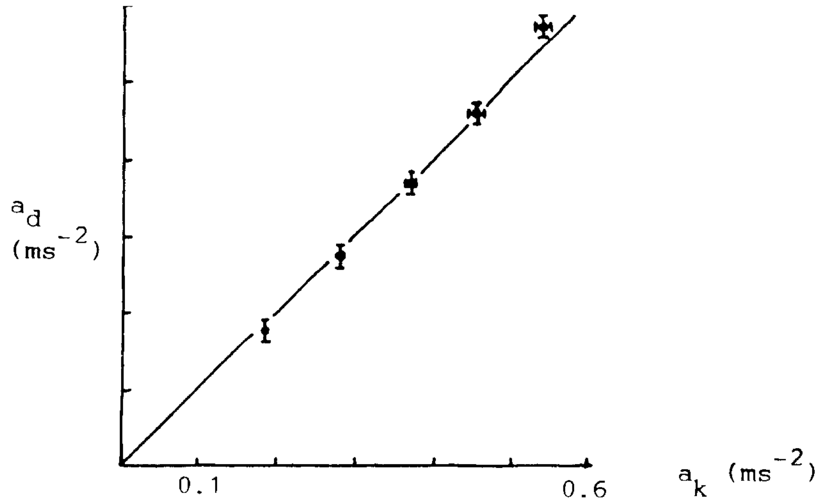


Fig. 3.52. Graph compares the dynamically measured acceleration of an airtrack glider with that measured kinematically.

Conclusion

The results reported above show that a pendulum accelerometer suitable for use with a linear airtrack can very easily be constructed. With a little more care, it is possible to construct a very accurate instrument which, when suitably calibrated, allows accelerations to be read directly off a scale.

Our intention is to introduce similar accelerometers into undergraduate mechanics laboratories at this university.

References

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2. J. Harris and A. Ahlgren, **Phys. Teach.** 4,314 (1966).
3. Merle Fisher, **Phys. Teach.** 7, 166 (1969).
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XXXIV. ACCELERATION IN A PENDULUM

John B. Johnston

To demonstrate acceleration in simple harmonic motion I recommend the use of a Project Physics accelerometer with ballistic pendulum suspension (Figure 3.53). This suspension, if assembled and operated properly, will keep the accelerometer fairly level, and thus, fairly accurate, throughout its swing.

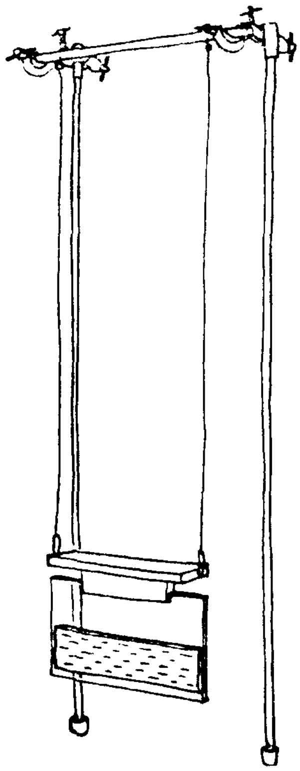

Fig. 3.53. Project Physics accelerometer mounted to show accelerations in a pendulum. Photo was taken at bottom of swing when velocity is greatest and the acceleration is zero.

To adapt the accelerometer, fasten the fluid container upside down in the wood block, and considering balance, insert a screw eye near the center of each end of the block. Possibly they can remain there permanently. A hanger may be made from a piece of 12.5 mm wood dowel about 40 cm long. Insert two screw eyes into the dowel matching exactly the separation of the screw eyes on the ends of the wood block. For long wear and adjustability, use a standard size paper clip with each screw eye. Measure out two pieces of strong thread about 80 cm long. Tie each thread to a paper clip on the hanger. With the two threads hanging down, mount and level the hanger on two support rods. Double V, swivel clamps are recommended.

Make the pendulum as long as possible, avoiding obstructions. Tie each remaining thread end to a paper clip on the block, keeping the block as level as possible. Using a pair of pliers, bend one of the paper clips until the block is finally level. Pull the pendulum aside a reasonable distance, and let it go. After a swing or two, you should observe a smoothly changing acceleration pattern throughout each cycle with the slope of the liquid greatest at the ends of each swing the zero when the velocity is maximum at the bottom of each swing. As usual, the accelerometer will read quantitatively as well as qualitatively, and you may pursue further study with it. For easy storage, simply detach the bottom paper clips from the block's screw eyes, and wind the threads and clips up on the dowel.

XXXV. LARGE SCALE USE OF A LIQUID-SURFACE ACCELEROMETER

Lawrence E. L'Hote

The following note describes a quantitative use of a liquid surface accelerometer in both linear and circular motion.

Each pair of physics students was provided with pre-cut pieces of plexiglas and accelerometers were constructed as outlined in The Project Physics Handbook.(1)

Table Showing Student Data for Linear Acceleration

Distance (m)	Elapsed time (s)	Accelerometer Scale Reading	Experimental Acceleration (ms^{-2})	Theoretical Acceleration (ms^{-2})
1000	9.9	2.25	23.1	20.4
1000	10.5	2.0	20.4	18.1
1000	9.0	2.5	25.7	24.7

Linear Acceleration

The day before the demonstration was scheduled, I marked off a 1000 m course on a little-traveled, flat section of a asphalt country road. A windowed van school bus was found to be an ideal vehicle to use because it could hold the entire class and could be maneuvered easily. The students placed their accelerometers level against the van windows and, using the lower gears of the automatic transmission, I drove through the 1000m course. Elapsed time and accelerometer scale readings were recorded for five runs in both first and second gears. Several 'trial' runs were made to familiarize the students. Also, it takes a little practice for the driver to produce an even acceleration rate throughout the course length. Although the class didn't take any data for deceleration, the reaction of the liquid surface to slowing was obvious.

Centripetal Acceleration

Four students were seated on a playground merry-go-round. The students were to center their accelerometers at specified distances from the center of the merry-go-round i.e. 30 cm, 50 cm, 80 cm and 100 cm. Other students were assigned as "pushers" and one student was to act as timer. Data from several students are shown in the table. It should be noted that as one used the accelerometer toward the center of the rotating platform the accelerometer scale becomes less accurate. At the 30 cm position the accelerometer, which is about 22 cm wide, does not indicate the true acceleration at exactly the 30 cm mark because the edge toward the center of rotation is 10 cm closer to the center while the outer edge is 10 cm further out from the center. Data at the 30 cm position reflects the amount of error involved. Although the students were advised to take readings on both left and right scales and average to eliminate some of the error, the students seemed to favor just reading the right-hand scale. It could be that the persons riding the merry-go-round considered the problem of just hanging on far greater in importance than taking precise data.

Table showing student data for centripetal acceleration. One revolution of the merry-go-round is 4.2 seconds.

Radius of Rotation cm	Accelerometer scale reading	Experimental acceleration cm s^{-2}	Theoretical acceleration cm s^{-2}
30	.8	.78	.68
50	1.2	1.18	1.12
80	1.8	1.76	1.79
100	2.5	2.45	2.24

Reference

1. Gerald Holton, F. James Rutherford, and Fletcher G. Watson (directors), **The Project Physics Handbook**, The Project Physics Course (Holt, Rinehart, and Winston, Inc., New York, 1970), pp.46-48.

XXXVI. CENTRIPETAL ACCELEROMETER

J.Unsworth and D.A.Unsworth

A force transducer can easily be made by attaching a strain gauge to a metal cantilever and applying a force **F** to the free end (Kuhl). A mass **m** fastened to the free end of this cantilever makes an accelerometer. This can be mounted on a turntable at a radius **R** to provide a convincing demonstration of the centripetal force relationship

$$\mathbf{F} = \mathbf{mv^2/R} = \mathbf{mR\omega^2}$$

where v is the tangential velocity and ω is the angular velocity.

A semiconductor (silicon) strain gauge (Kyowa type KSP-2-E4)+ can be cemented on to a stainless steel cantilever (Young's modulus 210 GPa, 85 mm long, 18 mm wide and 0.5 mm thick) at about 40 mm from the fixed end using Aron Alpha quick set adhesive or Philips strain gauge cement PR 9247. The fixed end is attached to the outside of a hollow stiff brass tube. One of the electrical contacts of the gauge is attached to a spring loaded brass rod which is inside and insulated from the hollow brass tube and the other makes contact with the outer tube.

A 12 mm wide, 5 mm thick rectangular aluminium bar is attached along a radius on the turntable. A thin Perspex strip with holes along its length is fastened to the aluminium as an insulator. A rectangular aluminium bar (12 mm wide, 5 mm thick), which has 10 holes drilled along its length at 10 mm intervals to match up with those in the Perspex, is screwed on to the plastic strip and the lower aluminium bar using nylon screws. The lower and upper aluminium bars are electrically connected to slip-rings on the spindle at the centre of the turntable, the Perspex keeping the two electrically insulated from one another.

The cantilever strain gauge (force transducer) can be mounted vertically in one of the holes so that the spring loaded brass rod makes contact with the lower aluminium bar and the brass tube makes contact with the upper aluminium bar on tightening a grub screw. Figure 3.54 is a diagram of the turntable showing the cantilever attached in position.

+ These gauges are available directly from the manufacturer Kyowa Electronic Instruments Co. Lts. 328 Toranomn. 2 Chome, Minatoku, Tokyo, Japan. Alternatively metal foil gauges can be obtained from Philips (e.g. PR 9833K) but the electronic amplification will have to be increased by about 60 times since the gauge factor of semiconductor types is about 120 whilst that for metallic types is only 2. Also the resistances in the other arms of the Wheatstone bridge may have to be changed and selected so as to achieve a balance in the no strain condition.

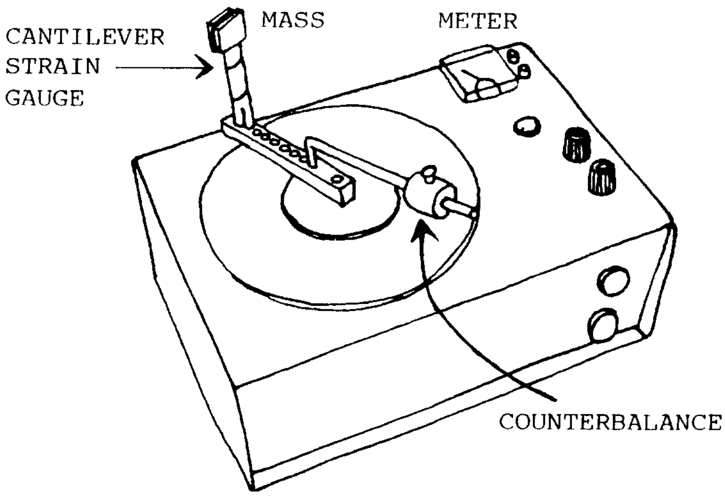

Fig. 3.54. Centripetal accelerometer system. The cantilever-strain gauge transducer with the mass attached can be moved to different radii and the counterbalance adjusted.

The two electrical contacts leading from the turntable spindle are connected to three other resistors arranged in a Wheatstone bridge configuration. The resistors were chosen so that they equalled the strain gauge resistance of 120 as closely as possible. To allow for slight differences of resistance a 1 k variable resistance was added so that the bridge output V_0 displayed on the meter could be adjusted to zero before starting the experiments.

The geometry of the cantilever and the Young's modulus of the steel resulted in a resonant frequency of 177 Hz with no attached mass which is well above any oscillations obtained with the mass attached. The gauge factor of 116, dimensions of the cantilever, Young's modulus and the position of the gauge resulted in a sensitivity after amplification by the CA 3140 differential amplifier of 0.47 VN^{-1}. This can easily be checked by placing the turntable so that its plane is vertical with the cantilever at its lowest position. By adding masses to the end of the cantilever a calibration graph can be produced as in Figure 3.55. The output increases with supply but this had to be limited to 4.8 V d.c. because the maximum current rating of the strain gauge is 20 mA. Two 1.5 V dry cells were used.

The output of the bridge is amplified using a differential input CA 3140 operational amplifier which was arranged as in the circuit shown in Figure 3.56 with feedback to give a gain of 100. Two 9 V dry cells were used as supplies for the amplifier. Finally the reading was displayed on a voltmeter mounted in the top of the turntable case. The voltmeter was made by converting a sensitive milliammeter by adding a 4.7 k series variable resistance so as to be able to get full scale deflection for the largest available radius **R** and the highest turntable speed for any particular mass **m**. Analogue terminals are provided to allow the output to be displayed on an x-1 recorder.

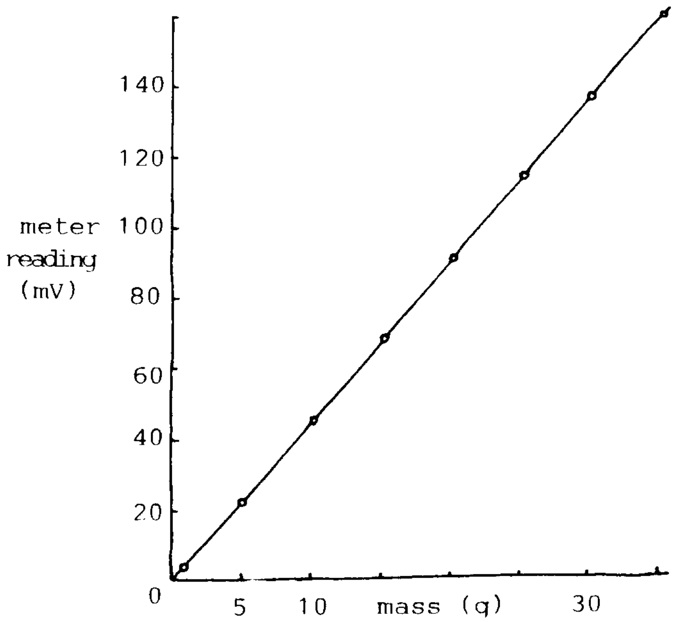

Fig. 3.55. Calibration of force transducer

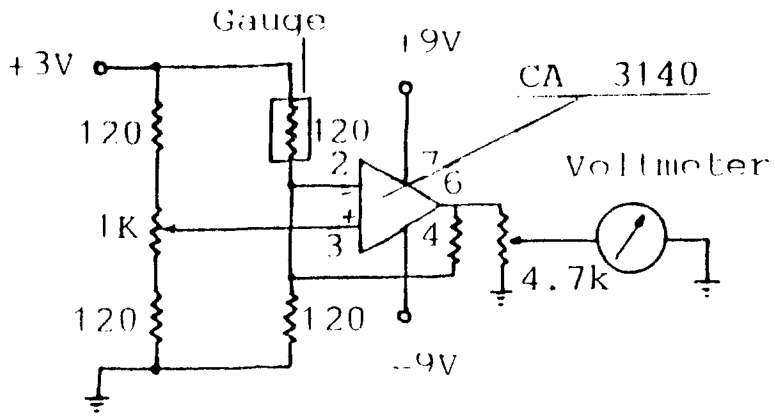

Fig. 3.56. Strain gauge differential amplifier circuit

Before starting any experiment it is important to add masses on the opposite side of the turntable to the cantilever to balance the system (like balancing the wheel of a car). This is quite easily done by rotating the turntable by hand and adjusting the position of the counter-balancing mass on the bar until the oscillation of the pointer of the meter is negligible.

To study the effect of the tangential speed of rotation at a fixed radius on a fixed mass the turntable speeds of 16, 33, 45, 78 revolutions/min can be used, the results of which are shown in Figure 3.57. The cantilever can then be fitted into the holes at different radii R and at one particular speed values of force determined. A graph is shown in Figure 3.58 of force against R. Different masses can then be attached to study the effect of inertia (pieces of weighed Plasticene proved to be satisfactory). The results are shown in Figure 3.59. An attractive feature of the experiment is the ease with which two parameters can be held constant whilst the other is varied.

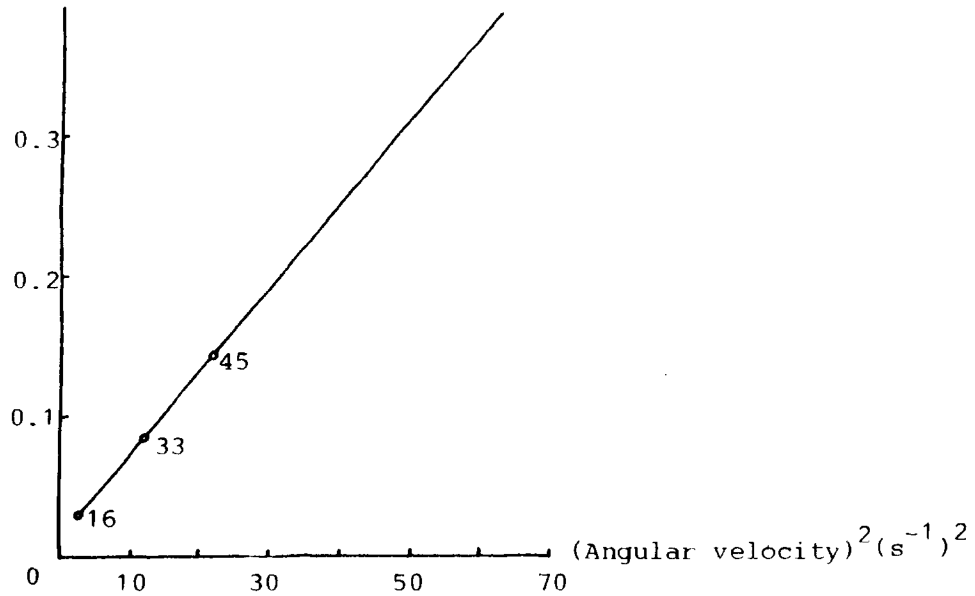

Fig. 3.57. Effect of angular velocity (fixed position and mass). Numbers on the graph show turntable speeds in revolutions/min.

Also, if well balanced, the cantilever can be faced tangentially so that at a constant velocity zero force is displayed as a zero reading, deflections of the needle only being detected when the turntable decelerates to stop. Finally the counterbalancing masses can be removed all together and the output displayed on an x-t recorder to illustrate how circular motion gives a sinusoidal output since essentially we are then considering a forced spring cantilever-mass system.

Acknowledgment

The authors would like to thank Mr. I. Paterson and Mr. B. Press for their technical assistance.

Reference

Kuhl H. Strain Gauges, Theory and Handing (Hamburg: Philips)

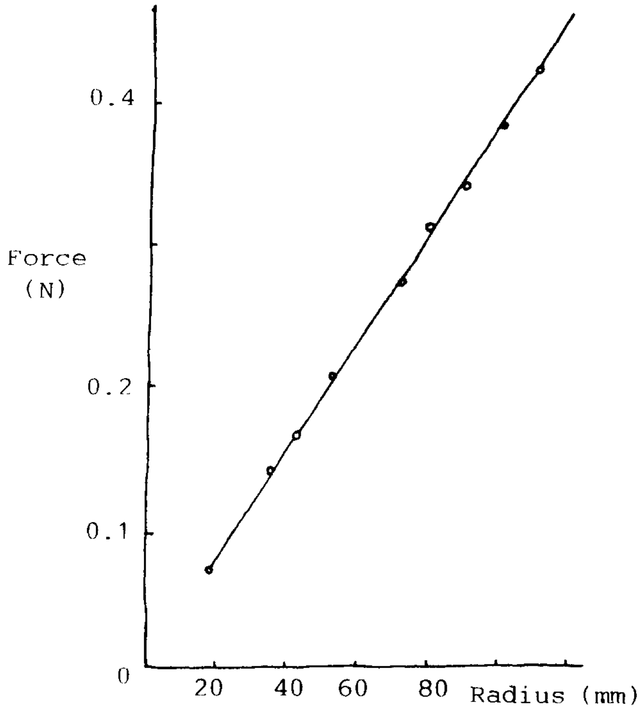

Fig. 3.58. Effect of radial position of transducer (turntable speed fixed at 78 revolutions/min, constant mass)

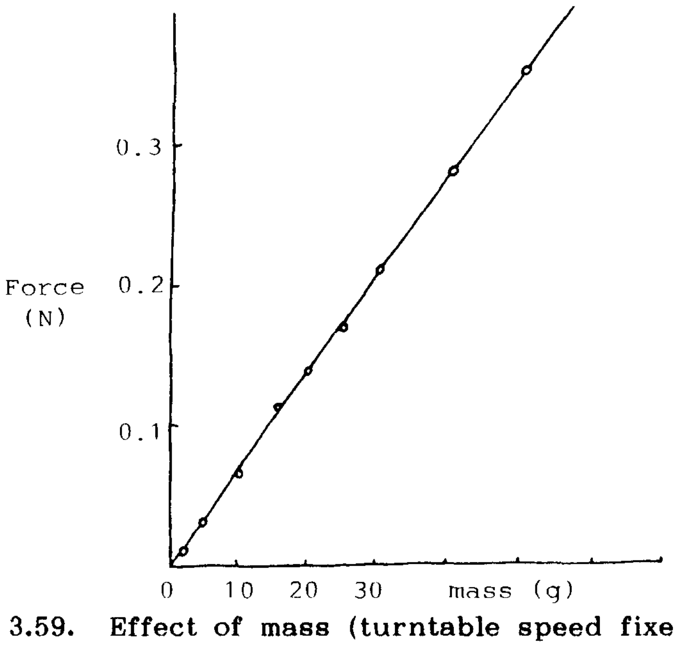

Fig. 3.59. Effect of mass (turntable speed fixed at 78 revolutions/min, fixed position)

XXXVII. DEMONSTRATING THE INWARD FORCE

R.L.Page

The difficulty in demonstrating and establishing this force satisfactorily in circular motion is that psychological experience tends to suggest an outward force in many examples where the human body is the moving object, and this is probably why many teachers find the approach mentioned above an easy way out. However there is one experimental demonstration where psychological experience suggests an inward force as the cause of circular motion, and Figure 3.60 shows the apparatus needed.

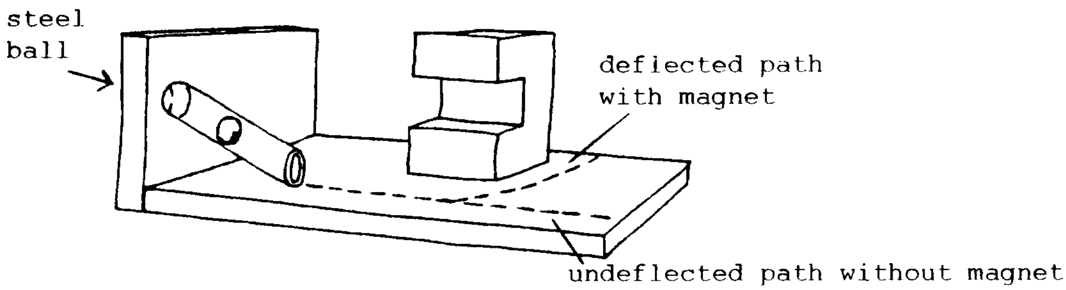

Fig 3.60

This model demonstrates that an inward force is necessary to produce circular motion. Without the magnet, the path taken by the steel ball when it is released down the tube is a straight one. With the magnet, deflection occurs into a circular path while the ball is crossing the magnet's field. By holding the steel ball near the magnet the class can feel the inward pull experienced by the steel ball. A brief mention can be made of planetary motion, along the lines that just as a stone falls to the ground, attracted by the force of gravity which is an inward force, so the earth in turn is attracted to the sun, and as a consequence travels in orbit round the sun. The term 'centripetal' can be introduced, but at this stage I think it is unwise to talk about action and reaction, and introduce 'centrifugal' force.

Note that the scientific experience needed is closely, in the example above, linked to the psychological, which I think is essential if good understanding is to be achieved. Most other examples, except perhaps for the stone on a string, tend to suggest an outward force psychologically and so the children do not 'feel' the inward force directly. These examples, such as the wall of death rider, the aeroplane looping the loop, the car turning a banked corner, the principle of gimbals, the flattening of the earth's poles, etc., ought to be left to a later date, when the class is more prepared to accept that psychological and scientific experience do not always agree. It is easy to see, if these latter examples are introduced first, why the static approach is taken of equating $\mathbf{mv^2/r}$ to an outward force, **F**, producing equilibrium.

XXXVIII. ROTATIONAL MOTION AND A TOPPLER (THE TOPPLER EFFECT?)

J.C. Siddons

Before discussing the toppler and rotational motion we will consider a toppler in linear motion. The toppler T (Figure 3.61) is an accurately made 2 cm. aluminium cube (supplied for density determinations). One half of a strip of paper S is taped to the base B, the other half to the cube. S acts as a hinge: it must be neatly creased along the line of topple.

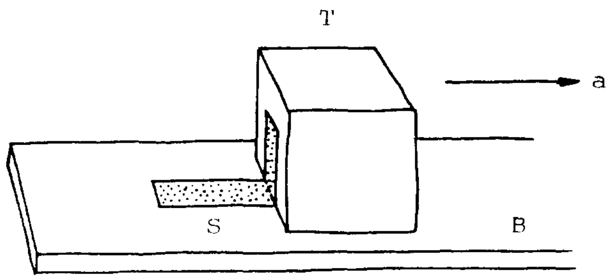

Fig. 3.61.

If the base moves to the right with a small acceleration nothing happens, i.e. the cube moves forward with the base. If, however, the horizontal acceleration **a** is increased, eventually the cube topples backwards. This happens when the horizontal acceleration equals the acceleration due to gravity, i.e. when **a** equal **g**. To see that this is so, consider the forces acting on the cube when toppling is about to take place (Figure 3.62). The reaction **R** of the base on the cube must then pass through the axis of topple and the centre of gravity **C**. The vertical component of **R** must equal **mg**, the horizontal component **ma**. The two components are equal and so **a** equals **g**.

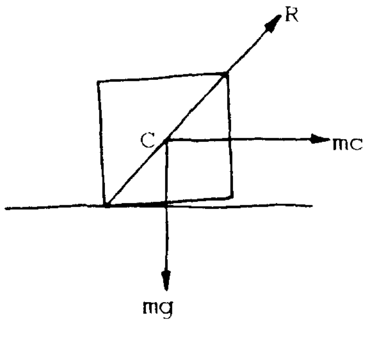

Fig. 3.62

If instead of a cube a cuboid was used whose height was **k** times its base, the horizontal acceleration to produce toppling would be only **a/k**. Such a cuboid can be made quite simply by sticking two cubes together.

To study rotational motion, place the toppler and its base radially on a turntable, preferably one with adjustable speed. The axis of topple must of course be on the side away from the axis of the turntable. Make **r**, the distance between the axis of rotation and the centre of gravity of the cube, 15 cm. Set the turntable rotating slowly, e.g. about 1 rotation a second. No toppling will take place. Gradually increase the rate of rotation. Eventually a gentle thud will announce that the cube has toppled outwards. Measure the rate of rotation, **n** revolutions/sec. The acceleration of the cube moving in its circular path to the centre is $r\omega^2$, i.e. $4\pi^2 n^2 r^2$. But the cube topples when the horizontal acceleration equals that of gravity and so $g = 4\pi^2 n^2 r$.

The experiment gives satisfactory values for **g**: the real purpose of the experiment is however not to find **g** but to become familiar by experiment with the idea that motion in a circle produces an acceleration. If a turntable with fixed speed is used, the cube will have to be placed at successively bigger distances from the axis until the critical distance for toppling is found.

Reference

Fell, J.I., S.S.R., 1957, Vol.38, No 135, pages 281-3, 1957

XXXIX. ON GOING ROUND AND ROUND

J.C. Siddons

J.I.Fell(I) has described an experiment with a ball-bearing in a circular groove mounted on a turntable. The ball comes to rest at a certain point on the quadrant of the circle, depending upon its curvature and the rate of rotation. A straight sloping groove can be used, with an adjustable stop (Figure 3.63). For a given speed of rotation, if the ball is less than a certain distance from the axis it stays against the stop. This stop is moved upwards in a series of small movements, or the speed of rotation is increased until the ball is just in unstable equilibrium, i.e. about to roll up to the top. From the speed of rotation, the slope and this critical distance a value of **g** can be obtained. It is generally rather low: this is because a momentary increase in speed of the turntable is sufficient to send the ball to the top. The speed of rotation measured with a stop-watch is the average speed: but the speed which matters is the maximum speed.

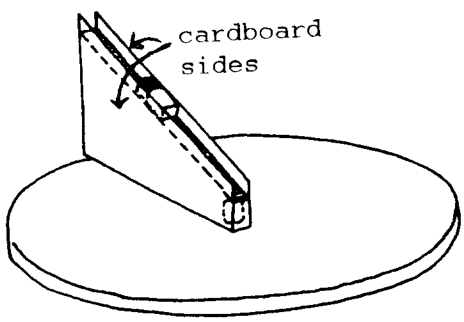

Fig. 3.63.

A ball-bearing in a parabolic groove makes an interesting demonstration. If the parabola is cut so that $y = (\omega^2/2g) \cdot x^2$ then the ball is at equilibrium at any point on the parabola. If the speed is slightly increased the ball rolls to the top; decreased, to the bottom.

The table gives **y, x** values in cm calculated for a speed of 78 r.p.m. and **g** 9.8 ms^{-2}.

y	0.086	0.345	0.777	1.39	2.16	3.11	4.23	5.33	6.99	8.63
x	1	2	3	4	5	6	7	8	9	10

It is difficult to cut the wood accurately near the middle since here the slope is very slight.

XL. H.F.Meiners (Editor)

Corn or wheat seeds are planted in earth fourteen days before the demonstration and rotated day and night on a turntable. They grow opposite to the resulting acceleration, or exhibit geotropism as shown in Figure 3.64. The acceleration experienced when the plants are grown on a 30 cm diam. circle and the turntable rotated at 78 rpm is approximately one gravity. Thus the plants will grow at a 45° angle. The result shows that the sensing element is at root level. This is a very effective corridor type demonstration.

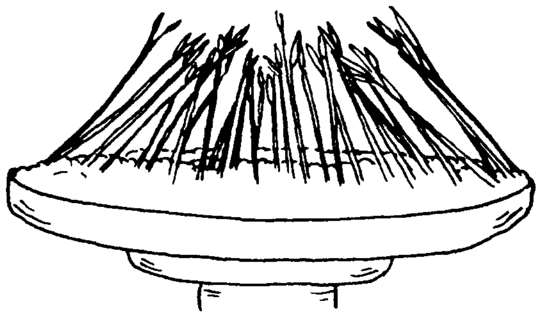

Fig. 3.64.

XLI. THREE ACCESSORIES FOR A ROTATING PLATFORM

James A. Riley and Oscar G. Fryer

A favourite piece of apparatus in our department is the rotating platform or turntable used to demonstrate various phenomena of rotational motion. In the course of many years of use we have developed several accessories that can be used in conjunction with the turntable to enhance its usefulness as a demonstration device if it is modified just slightly.

Our platform (1) is typical of those available from many scientific supply houses. It is made of heavy cast iron, approximately 40 cm in diam. and is mounted on a tripod base. The modification consists of inserting a pulley approx. 1 cm thick by 20 cm in diam. between the upper disc and the support bearings. The pulley is made of wood and is easily turned out by anyone with access to a wood lathe. The modified turntable is then mounted at one end of a simple wooden platform. A second pulley with vertical shaft and crank is mounted at the other end with a V-belt passing around both pulleys. A bolt passing through one foot of the turntable and a slot in the platform allows the position of the turntable to be changed so that the tension in the V-belt can be adjusted. Although our crank-shaft assembly consists of a brass rod passing through brass bushings at the top and bottom the entire assembly could be made of hardwood or of whatever materials happened to be available.

Thus mounted (Figure 3.65) the turntable can be rotated by means of the crank. The relatively large moment of inertia of the turntable insures that with very little practice one can rotate the turntable at a constant and easily measured angular velocity. If a freely turning table is desired the V-belt is easily dislodged by pushing down on it while turning the crank. It can be replaced just as easily by holding part of it in the pulley groove while turning the crank one turn, much like replacing a bicycle chain on its sprocket. The accessories described in this article are mounted on the turntable by inserting their central supporting rod into a 4 cm diameter by 10 cm deep well in the center of the table. In the original design of the turntable as it comes from the supplier this well served as a countersink for the large screw at the bottom which acts as an axle and holds the platform on its bearings. With no modifications it serves equally as well in facilitating the mounting of our accessories.

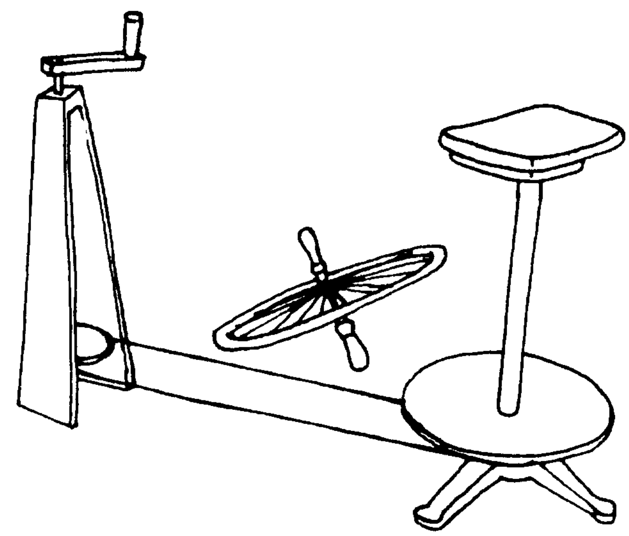

Fig. 3.65. Turntable mounted on platform with V-belt, pulley, and crank for rotating apparatus. Variation I, a one-legged stool is mounted on the turntable.

Variation I: Conservation of angular momentum

A very well known and impressive demonstration has a student sitting on a stool mounted on the rotating platform while holding a weight in each hand. As the student brings the weights in close to his body his angular velocity increases markedly giving a vivid demonstration of the conservation of angular momentum.

Although a regular four-legged stool will fit on the turntable a much more stable stool can be easily made for such a demonstration. Our stool (Figure 3.65) consists of an oval shaped seat mounted on a 5 cm diameter wooden rod turned at the lower end on a wood lathe to fit snugly into the well in the turntable. The one-legged stool is easily put into place and removed, is always centered, and there is no danger of its tipping off while the platform is in motion.

For this demonstration the platform is used in its free-wheeling mode with the V-belt off the pulleys. After the initial demonstration with the weights it is very impressive to follow up by placing a rotating, weighted bicycle wheel in the student's hands with the instructions to raise it over his head. The resulting sensations never fail to arouse interest and soon a line-up of volunteers forms to take their "turn" on the table.

Variation II: Gravity defying goblets

The phenomenon demonstrated by this variation may be familiar to those students who have ridden a carnival ride in which they are held by "invisible forces" against the side of a large rotating cylinder while the floor drops out from under them. Our second accessory (Figure 3.66) is simple but very effective in getting attention.

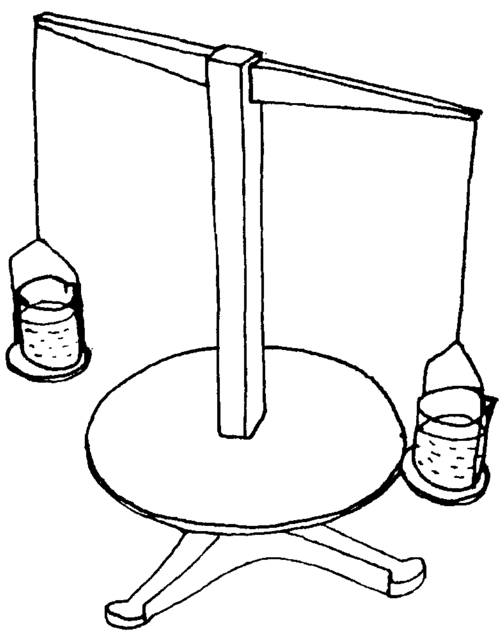

Fig. 3.66 Variation II, mounted on the turntable, stands ready to be rotated with two Florence flasks of water on its platforms.

Again designed to fit into the central well of the turntable, it consists of a T from each arm of which a simple platform is suspended by means of strings. On each platform a flask or beaker of water is placed. (A champagne glass or goblet is much more dramatic if they are available and one doesn't mind risking the occasional accident that occurs). The turntable is rotated by means of the crank and V-belt with increasing angular velocity until the goblets are almost horizontal. Care must be taken so that there is enough room for the platforms to rotate in ever widening circles as the angular velocity increases, otherwise an even more spectacular demonstration occurs as the fast moving goblets hit some stationary object.

The ensuing discussion on the forces involved in keeping the goblets on the platforms can be very valuable for classes at any level. Advanced classes can make a detailed analysis by measuring the parameters involved and using them to calculate **g** or to verify the equations of motion involved.

Variation III: Direct measurement of centripetal force

Our third variation on this theme is an accessory which allows one to measure the centripetal force on a mass moving in a circle of known radius at a known speed. One then has the option of again verifying the standard equation for centripetal force:

$$\mathbf{F} = \mathbf{m}\mathbf{v}^2/\mathbf{R} \qquad (1)$$

or one can have the student plot force versus positive and negative powers of **v**, **R**, and **m** and more or less inductively determine the form of the equation relating the force and these three quantities. (When the plot yields a straight line then the force is proportional to the quantity against which it is being plotted.)

The device consists of a rod with an arm at the top which supports two pulleys. The bottom end of the rod fits snugly into the central well of the turntable. A string is tied to the body to be rotated. It passes over the two pulleys and half way down the length of the rod through an axially drilled hole where it is fastened to the upper end of a screen door spring. The lower end of the spring is held at the bottom of the hole by a bolt passing at right angles through the rod. The position of the upper end of the spring is indicated by a length of wire cut from a coat hanger and bent into a shape resembling the Greek letter θ or a distorted S. The central portion of the indicator passes through a slit cut approximately one half the length of the rod and is fastened to the upper end of the spring. The two semi-circular portions pass around the rod in opposite directions so that the indicator's position can be noted on either of two scales running vertically up the sides of the rod. Weights hung on the string while the apparatus is stationary allow one to calibrate the apparatus so that the indicator yields a direct reading of the tension in the spring. When the turntable is rotated at a constant rate the mass at the end of the string moves in a circle subject to the forces of gravity and the tension in the string.

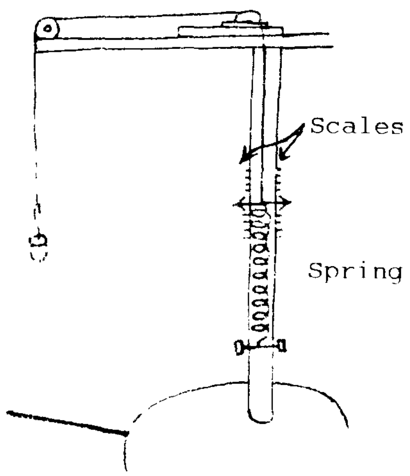

Fig. 3.67 Variation III, in the process of being calibrated, stands mounted on the turntable.

The entire modification and set of three accessories can be made in a few hours time in a home work shop or as a project in a school wood-working class if you are fortunate enough to have one. Once assembled the apparatus will afford your students the opportunity to experience the phenomena of rotational motion rather than just hear about it.

Reference

1. Cenco No. 74790-000

XLII. PARABOLOID OF REVOLUTION P.M.Sutton (Editor)

A cylindrical glass jar is accurately centered on a rotating table. Colored water is placed in it, and the cylinder is rotated. After viscous forces have brought the water to a steady state of revolution, the surface becomes a paraboloid of revolution (Figure 3.68). If the jar is just half full at the beginning, the vertex of the paraboloid will reach the bottom of the jar just as the liquid reaches its upper edge. A short lighted candle on the end of a stick may be lowered to the bottom of the jar to show the absence of liquid at the center.

Clear water covered with colored castor oil so as to fill completely a cylindrical jar closed at the top will, on rotation, show a paraboloid of oil surrounded with water. Any two immiscible liquids of different densities may be used.

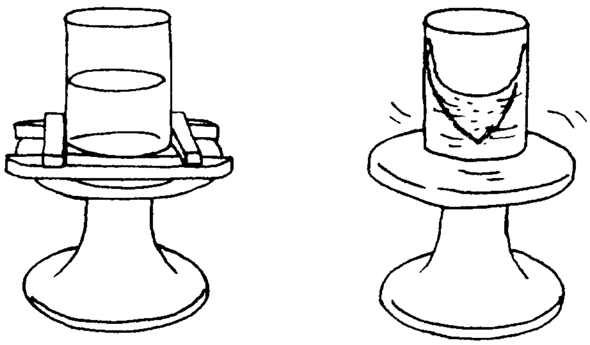

Fig. 3.68. A. Battery jar with water at rest.
B. Same in rapid rotation showing paraboloid of revolution.

XLIII. PARABOLIC MERCURY MIRROR

P.M.Sutton (Editor)

A circular pool of mercury (or a Petri capsule) may be rotated to make a parabolic mirror (L-25). The focal length of the mirror is $g/8\pi^2n^2$, where **n** is the speed of rotation in revolutions per second. A 6 v automobile headlight bulb is placed above the center of the mirror, and the mercury is rotated at constant speed for several minutes. The height of the bulb is then adjusted until the reflected light just fills a circle of the same diameter as the pool of mercury. The measured height of the bulb above the vertex of the mirror and the computed focal length should agree closely.

XLIV. WHIRLING BUCKET OF WATER

P.M.Sutton (Editor)

Perhaps not all students are acquainted with the time-honored trick of swinging a bucket of water in a vertical circle at arm's length without spilling the water.

XLV. MEASUREMENT OF KINEMATICAL QUANTITIES BY AN ON-LINE PERSONAL COMPUTER

Giorgio Fontana and Vittorio Zanetti

Teachers will agree that students are often bored in the study of kinematics and dynamics by too many calculations, especially when deriving instantaneous speeds and accelerations from a consideration of data related to displacement vs time of the moving body. We try to avoid this pedagogical weakness in physics teaching, using a personal computer to carry out the routine calculations and to display graphs.

Our equipment is shown in Figure 3.69: it is essentially a dynamics cart, for example, the PSSC or PP kind, that carries a small box. In this box there is a low powered lamp and also a phototransistor that receives the light coming from the lamp after reflection from a black and white striped sheet of paper. If the narrow beam of light is reflected by a white stripe, the electrical signal from the phototransistor will be high; if reflected by a black stripe, the signal will be low. The signal is amplified, compared with the average signal with respect to time and then sent to the input port of an Apple IIe computer (the cassette input is the most fitting). In Figure 3.70 the electrical circuit of the box is shown. Without the need for any commercial interface, the computer counts via software the number of transitions, i.e., double the number of stripes seen by the optical pick-up, in a given amount of time - 1 s for slow motions or 0.1 s for those faster, depending on choice. Part of the program is written in machine-language, to be able to count the frequency of the lines seen, and thus the speed of the cart itself.

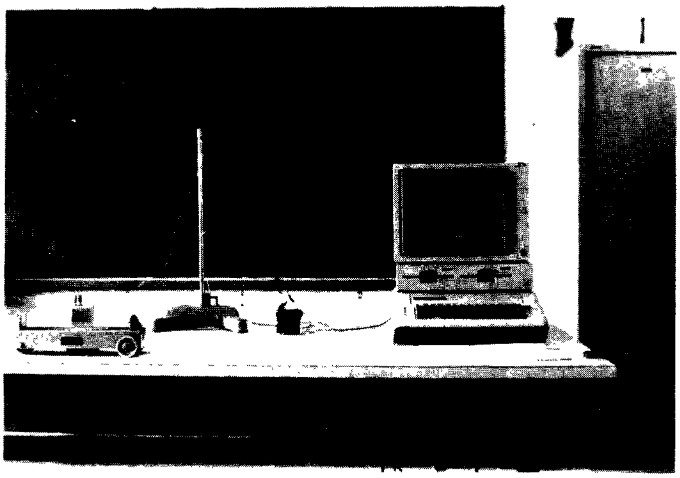

Fig. 3.69. Set up referring to Newton's Second Law. Clearly noticeable on the tabletop is the striped sheet of paper.

We wish to point out that the scanning beam of light must be very narrow, and so must the width of the stripes, in order to gain high spatial resolution. Instead of using a lens to obtain a narrow beam, we were able to obtain this by just using a small slit in front of the lamp. Because "home-made" apparatus was used, the cost of the whole equipment was kept very low, especially when compared with other methods requiring an expensive interface for the computer.

The pick-up box is powered through a long and flexible electric cord, hanging from a high stand. This cord consists of three wires, one for powering the device, one for sending the signal to the input port, and the other being common. In a forthcoming version we intend to substitute this awkward "navel-string" connection with a radio-transmitter powered by dry cells. The computer records the data, and displays this in real time, plotting the graph of v vs t. The fact that students can follow the plot while the cart is moving, underlines the principal features of different kinds of motion better than when one draws a graph after the cart has come to a halt.

Then students can operate two cursors: one to choose the time t_1, the other for time t_2, so that the computer calculates the average acceleration between these two times. Now, if this procedure is repeated, and if the time intervals are very short, it is possible to obtain many values of acceleration. These values are reported one by one in a new graph (a vs t), directly above the first graph (v vs t), in a manner similar to the way students follow more traditional methods. In this procedure, very interactive indeed, students reinforce conceptual understanding.

We even point out that if the number of stripes per metre is very high, as in our case (681 stripes per metre), then the number of stripes seen in one tenth of a second is high enough to allow the calculation of an almost instantaneous speed, in most cases.

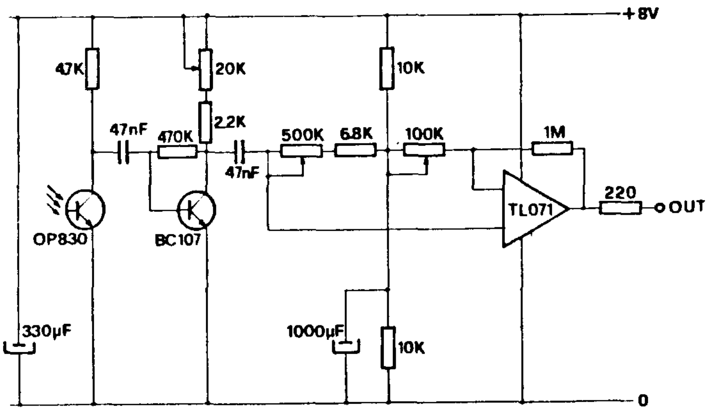

Fig. 3.70 Electrical circuit of the optical pick-up.

This method of studying motions is not completely new. Other authors (1)-(4) in fact used something similar, but they had to use expensive interfaces. Furthermore, some used a static optical pick-up and a moving modulator of light (a "comb" attached to the cart). But the comb must be necessarily much shorter than our striped sheet of paper, which can be as long as one wants. Hence, with our method it is possible to study entire motions, not only short parts of them. (By the way, the striped sheet of paper can be obtained by a graphical printer: everything from computer science!)

We found it very natural to use this method for studying the following motions:

(i) Inclined plane, with different slopes. (See Figure 3.71);
(ii) Second law of dynamics, with different forces and masses. (See Figure 3.72);
(iii) Inertial balance, made up by a cart pulled by two soft springs, on the top of a well levelled table. (See Figure 3.73).

Errors are substantially lowered using a sheet of paper with a great number of equidistant stripes, as we remarked before.

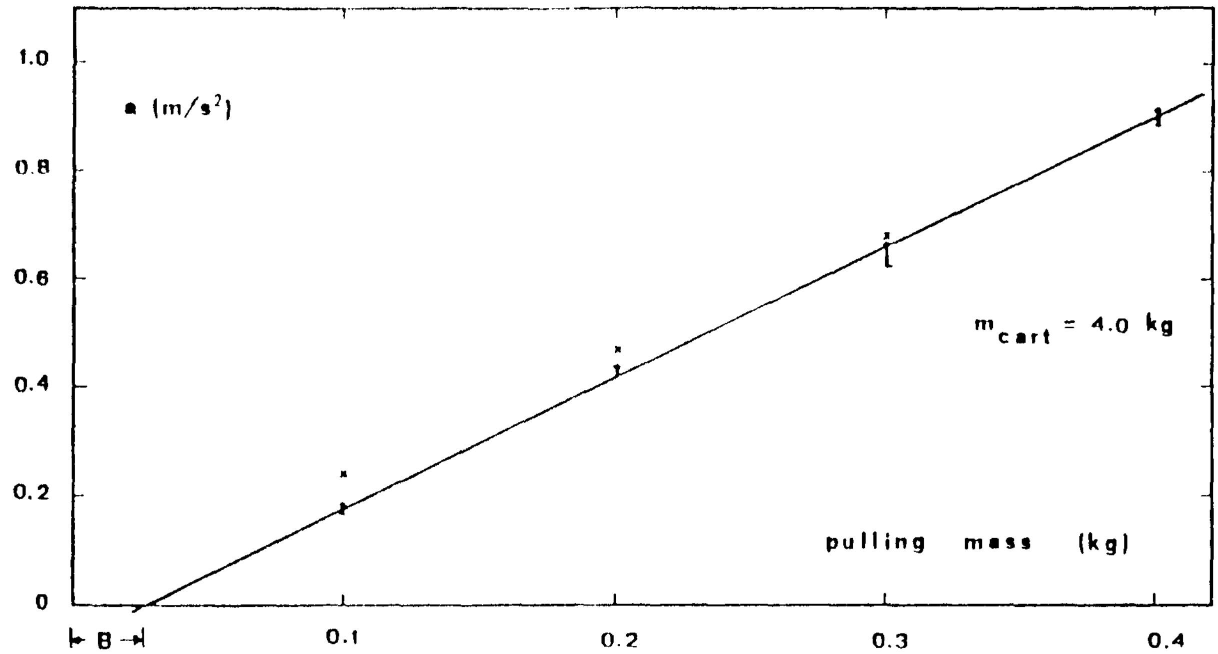

Fig. 3.71. Data obtained with an inclined plane, by varying the inclination (Solid line). The dotted line represents the theoretical relation a = g.sinα (where = tg^{-1} h/l). The quantity F depends upon friction and rotational inertia of the wheels. It measures the slope of the inclined plane at which the speed of the cart should be constant. Cart mass = 1.21 kg.

Another consideration is the non-complete reliance of the computers. . . especially if a person is not an expert in this science. To test this, one of us (V.Z.), shy on computers, decided to check the accuracy by attaching not only the optical pick-up, but also the paper tape of a PSSC timer to a cart moving on an inclined table. The accelerations calculated via the least-squares method, using the values of speed obtained with the two devices, were found to be equal within a 3 percent level of uncertainty. (In this trial it is essential to compare the data referring to the same part of the descent on the incline).

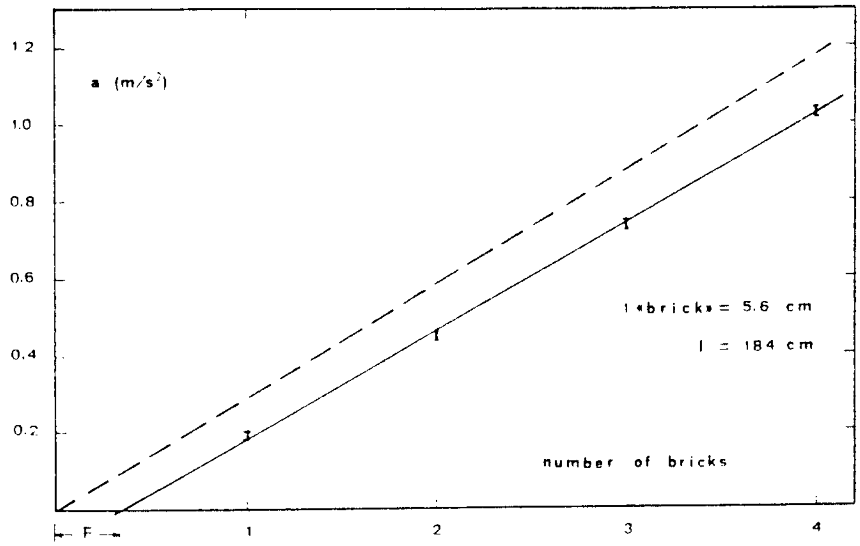

Fig. 3.72. Newton's Second Law, with the classical experiment of cart, pulley and weight. The quantity B depends upon the pulling force needed to compensate for the total friction. The expected theoretical acceleration, without friction, is shown with cross marks. Rotational inertia of the wheels was neglected.

APPENDIX: Frequency measurement

In our case, speed means frequency, so the system requires a frequency meter. The cheapest way to produce this is by an assembly language routine. When the program has to sample the frequency, it simply calls the measuring routine, and this routine returns the value of the frequency with an accuracy better than 1%. The routine only requires 102 bytes of the 6502 microprocessor machine language. It "looks" at the cassette port of the Apple II repetitively (11,609 times per second in our program) and counts the number of transitions between low and high level and vice-versa that occur during the measuring interval. The routine is time balanced to also have good linearity. A problem arises from the fact that if a transition is observed, the program must increment the register by one, but if a transition is not observed it must lose the same amount of time used by the microprocessor to increment a register. A perfect balance ensures an optimum of linearity.

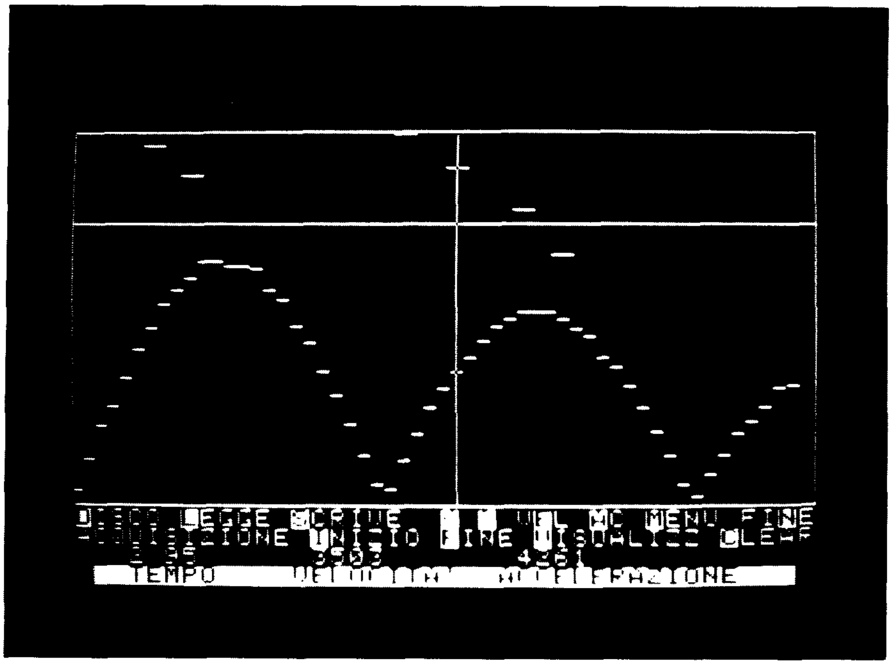

Fig. 3.73. Inertial balance. The computer's display is divided in two parts: below the graph v vs t is shown; above, the graph shows a vs t, obtained point by point by a student, using the vertical line shown, commanded by a cursor to choose the time intervals between which the computer calculates the acceleration. Notice that our optical device is not able to discriminate between the cart's velocity towards the right or left, so that both the semiwaves of the damped SHM are drawn above the x axis.

The theory of sampling shows that this software frequency meter can measure the frequency of a 50 per cent duty-cycle square wave up to 5800 Hz. This is acceptable for our purpose.

Should anyone like a copy of the program, please contact the authors at this address: Dipartimento di Fisica, 38050 POVO (TN) - Italy.

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XLVI. FEELING THE CORIOLIS

Fred T. Pregger

We frequently talk about the Coriolis effect in physics and earth-science courses citing its effects on air and ocean currents and on projectiles as evidence that the earth is turning on its axis. In teaching physics we deal with it as an example of fictitious forces which arise in rotating or otherwise accelerated reference frames.

There are several lecture demonstrations that show this effect. However, one day it occurred to me that the "experiment" described below ought to work, so I went to an amusement park and tried it on the appropriate piece of apparatus. It works beautifully.

If you really want to **feel** the Coriolis effect, find the nearest merry-go-round. Invest the fare and take a ride, but instead of mounting one of the horses, do what the ticket taker does; walk on the carousel while it is in motion. Try to walk briskly from a point on the outer rim straight in to the corresponding point on the inner rim. You will be walking from a part of the platform that has a certain tangential velocity to your right (based on the usual direction of motion of carrousels in this country) to a point which has a lower tangential velocity since the radius is less, and the angular velocity is the same. (This is analogous to moving from a point on the rotating earth's equator to a point on the same meridian at, say, 40° north latitude.) You will feel a very strange "force" in a direction you don't expect. Unless you are careful, you will find your motion deviated to the right and you will miss the point you are aiming for. You can reverse the procedure and walk rapidly from the inner rim to the outer rim, and again you will be forced to the right. You can see why air currents and ocean currents and projectiles behave as they do. It is hard to believe that you are dealing with a fictitious force. It feels real!

Try it yourself and suggest that your students try it the next time they visit an amusement park or seaside resort. Bystanders may think you are a little strange, but you will have felt the Coriolis "force".

An excellent discussion of the theory involved in the "Coriolis pseudo force" is given in Taylor, **Introductory Mechanics**, John Wiley, New York, 1963, pp. 249-257. See also "The Case of the Coriolis Force," M. Correll, **Phys. Teach.** 14, 48 (1976).

XLVII. CORIOLIS FORCE APPARATUS

T. Walley Williams III and F.E. Christensen

Strange things seem to happen when one describes the motion of a particle in a rotating set of coordinates. Mathematically it is quite simple to show the derivation of acceleration (or force) terms - otherwise missing in an inertial reference frame - if, for instance, a coordinate system is allowed to rotate within a fixed reference frame. Because of the nature of the apparatus to be described, the general mathematical problem degenerates to a case in which the angular velocity of the rotating coordinates is constant and the linear velocity of the particle is assumed constant in the inertial system. The apparatus is essentially a board (or disc) rotated in a horizontal plane, with water flowing at constant speed through a tube connecting opposite ends of the board (see Figure 3.74).

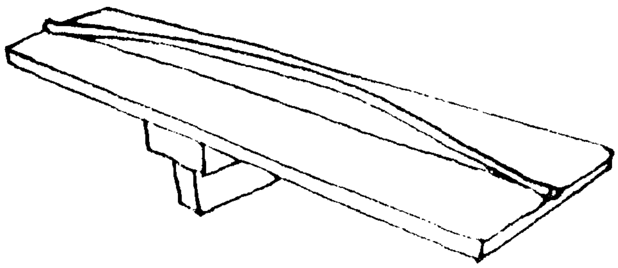

Fig. 3.74. Top view. Photo shows pattern obtained when water flows through tube as table is rotated.

Under the set of imposed restrictions two forces - the centrifugal and Coriolis forces - are apparent to an observer in the rotating system. These forces are often called fictitious since they do not arise from an interaction with other bodies. The forces arise from the fact that the motion of the particle is described in the rotating coordinate system.

The model described in this article differs slightly from apparatus (1,2,4) developed and used for many years. In particular, it is similar to the apparatus (3) described by Professors A.B. Mladzeevskii and M.V. Lomonosov, University of Moscow.

In the Russian model the apparatus consisted of a vertically mounted disc approximately one metre in diameter which could be rotated about a universal axis. Across the front and along a diameter a flexible tube was placed. The end of the tube was connected to a special hub that allowed water to enter at one port and exit at a second opening. In operation the apparatus was connected to a water faucet so that water can flow through the tube when the disc is held stationary or rotated. When water flows through the tube while the disc is rotated, a definite curvature of the tube results from the combined motion of disc and the water.

The apparatus we have designed has modifications from the Russian model and is easier to construct. A flat board (0.3 m x 1.3 m) was substituted for the disc and, for the sake of convenience and portability, a closed water system was used. Rotation of the board is in the horizontal plane. The motor-pump assembly is mounted under the board and near the axis of the system. Brass elbows (12.5 mm I.D.) were used at the corners. The black gum rubber tube connects the brass elbows that are mounted at the extremities of the long dimension of the board.

Ordinarily when the system is at rest or the water is not flowing in the tube, the tube lies along the radii - the black lines drawn from the center. When the system is set into rotation and water flows in the tube, the Coriolis force is in the horizontal plane of the tube and perpendicular to the radius drawn from the center of rotation. The magnitude of the Coriolis force is proportional to the angular velocity of the system and the linear velocity of the water, and the direction of the force is reversed when either the angular velocity or the linear velocity with respect to the center of the system is reversed in direction. If the rotation is counter-clockwise and the flow of water from left to right (Figure 3.74 or 3.75), the rubber tube is pulled away from the radii lines as shown.

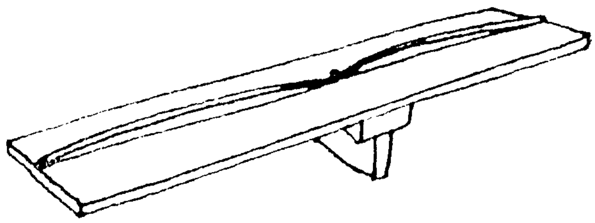

Fig. 3.75. Top view. Center of rubber hose fixed at axis of rotation. Pattern obtained when water flows through tube as table is rotated.

The various sections of the board can be marked by using dashes, solid lines, or discs (colored). Colored discs and tape (or paint) were used on the apparatus. Markings of this kind make it possible to identify the direction of flow of water and direction of the Coriolis force. The apparatus is not equipped with a flow reversal valve, which though desirable is not necessary since the direction of the angular velocity of the table is quickly and easily changed. One clamp shown in Figure 3.75 holds the center of the rubber tube fixed at the axis of rotation. We believe that it is pedagogically desirable to add this feature to the apparatus. If the demonstration begins with this arrangement of the apparatus, there arises the question about the pattern that the tube assumes - whether it is an S curve or a pattern shown in Figure 3.75. It is necessary, however, that the tube be slack in order to make the loops visible without having to go to high angular speeds. For this reason the clamp at the left-hand end of the apparatus is used to adjust the tension in the rubber tube.

On the latest model the electrical connection to the motor driving the pump is made through a phenolic slip-ring assembly and a pair of brushes.(5)

Acknowledgement is herewith given to Mr. Noel de Leon, Columbia University, for his cooperation and help in the construction of the apparatus.

References

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4. AAPT Apparatus Competition, **Am. J. Phys.** 27, 675 (1959).
5. Zeno Plastics Company, Pump Division, 444 E. Gardena Blvd., Gardena, California. Model No. B-300.

XLVIII. FOUCAULT PENDULUM AND THE CORIOLIS EFFECT

R.D.Edge (Section Editor)

It is difficult to put into words simple explanations for the apparent motion of pendulums and missiles seen by an observer on rotating system. Here are two experiments to make the explanation easier, requiring only straws, paper clips, sticky tape, string, a book, and a marble to perform.

Fasten three paper clips together, and push them into the ends of the straws, as shown in Figure 3.76. Six straws are fastened together by the corners in this way, to form a tetrahedron. (This provides a useful technique to build regular figures up to an icosahedron.) Tape may be used to fasten the corners if clips are not available. A marble is attached to a piece of fine string or a thread, using tape, and the other end fastened to the apex of the tetrahedron, allowing the marble to swing freely. Set the pendulum swinging and rotate the bottom of the tetrahedron. The base goes round but the pendulum does not. The equivalent pendulum on the earth would be at the North or South Poles. To demonstrate this, place the pendulum over the center of the polar map of the world in Figure 3.77, and rotate the map with the pendulum swinging. The fictitious force which appears to rotate the pendulum is called the Coriolis force.(1)

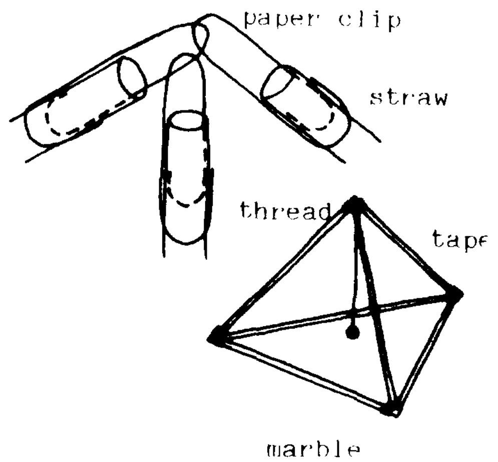
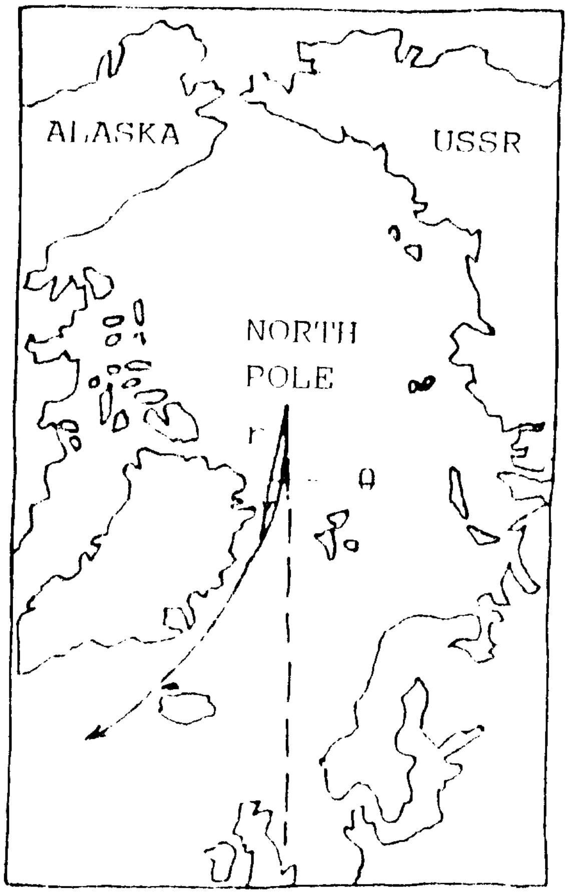


Fig. 3.76. A drinking-straw pendulum support.



TRAJECTORY
OF
ROCKET

Fig. 3.77. The actual path of a rocket launched from the North Pole.

A second experiment demonstrates the Coriolis effect on a projectile. Tape a fairly heavy book closed, and suspend it level, as shown in Figure 3.78, by four strings fastened underneath. The strings tie together above the book and are fastened to one string which is attached to a support such as a table top some distance above. Tape a sheet of plain paper to the top of the book. Dip a marble in a cup of water, start the book spinning, and roll the marble onto the paper on the book. The water on the marble will leave a quite obvious track on the paper. Replacing the plain paper with the map of the North Pole (Figure 3.77) is a help when referring specifically to the earth. Try rolling the marble more or less rapidly, and spin the book fast and slowly. It is also interesting simply to drop the marble on the paper, and see how it travels outward. The experiment is qualitative - the general mathematics of rotating systems is quite involved and probably is not worth tackling at an elementary level, except perhaps for special cases, such as a marble with uniform velocity v starting from the axis of rotation of a book spinning with angular velocity ω. Then, its position after time t in rotating polar coordinates on the paper stuck to the book is $\theta = -\omega t$, $r = vt$. An extension of this is a projectile fired from the North Pole. The course of such a projectile traveling at 1110 km h^{-1} (somewhat below the speed of sound on the Earth's surface) fired originally towards London, is plotted.

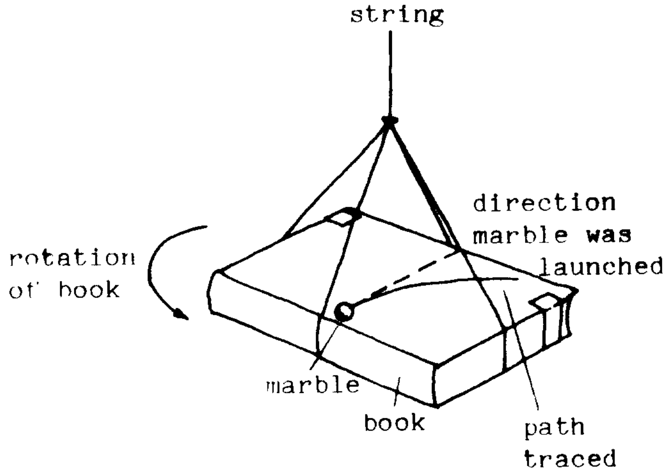


Fig. 3.78. Demonstrating the Coriolis effect on a projectile.

Robert Romer has an interesting article in the **American Journal of Physics** [49, 985(1981)] on the motion of balls on turntables, where he points out a nonslipping ball performs circular motion with 7/2 the period of the table, while tilting the table produces a progressive cycloidal motion sideways, and not downhill.

Reference

1. For an explanation of the Coriolis force see **Phys. Teach. 14**, 48(1976).

IL. THE CORIOLIS EFFECT AND OTHER SPIN-OFF DEMONSTRATIONS Lester Evans

In attempting to "make clear" to our students some of the not too obvious physical principles, we teachers use elaborate vector diagrams, mathematical wizardry, a considerable amount of hand waving, and many statements such as "it can be shown". After these exasperating experiences, usually brought on by a lack of good demonstration or laboratory equipment, the teacher is left with the feeling that his efforts were in vain with regard to the real concept. It was difficult, for example, for me to feel successful with the Coriolis effect. I am proud to say I have solved this problem completely with the demonstration described below. To my delight, I was also surprised by several spin-off ideas that occurred to me while performing the exercise.

The demonstration allows for direct student involvement (which is the best kind!) and the equipment has other applications making it even worthwhile to construct. Some of these "since you have it set up" applications will be described later.

The equipment consists of a heavy rotating platform (Cenco #74790-000 or equivalent), a 5 cm by 30 cm by 4 m long pine board, two large "C" clamps, two backs from broken chairs, one trash can, several tennis balls, and two brave students of about equal mass. Tables and chairs are moved from the center of the room, a convenient spot in or outside the building is located, so that a circular area about 5 m in diameter is available. Going outside is not a bad idea since a little exposure to curious sightseers of the fun we have in physics may help future enrollments. Place the rotating platform in the center of the area with the board centered across the platform and clamped firmly. The trash can (or bucket) is positioned at the center and the two students are seated at the ends of the board facing inward. The chair backs were added as a safety measure but the exercise can be performed without them.

Arm each of the students with a few tennis balls and gently set the whole thing rotating at about one revolution in 5 or 6 s. Ask one of your students to gently toss a ball into the trash can - !! You are now a successful teacher. The concept is clear and the vector diagrams are now meaningful. The effect is very dramatic and was a grand surprise to this old physics teacher the first time it was used in my classes.

Tossing the ball from student to student is also interesting and some may readily achieve the skill to toss it to themselves on the opposite side of the circular path. During this latter "fun and games" segment, have the rest of the class determine if the horizontal flight of the ball is a straight line or curved. You may suggest they hold a book or their hands to block their view of the rotating system.

Now, while you have it set up anyway, try some of the following spin-off ideas. For this part, have your two students seated but facing outward as near the ends of the board as possible, knees up and feet on the board. Give the system a slow rotation and command your students to slowly slide themselves inward at about 10 cm per revolution. Since they cannot observe each other, you may need to give them verbal instructions to keep the system balanced. Conservation of momentum! Now draw your vectors.

In this demonstration, you also may experiment with a "student fit to the equation" $F_c = mv^2/r$. If given a sufficient initial rotational speed, the students find it very difficult, if not impossible, to force themselves inward beyond a certain point until the system slows.

The angular momentum of this low friction system is nearly constant, and each student can be considered a "point" mass with angular momentum mvr. Thus, reducing the distance from the center causes an increase in the tangential velocity and the centripetal force (mv^2/r) [For constant (mvr), $F_c = mv^2/r \dashrightarrow m^2v^2r^2/mr^3 = K/r^3$], the effort required of the students to push themselves inward, increases dramatically.

A test of the centripetal force equation can also be demonstrated by having one student sit in the center holding a spring scale attached to a string and to a dynamics cart. The cart can be held at any radius of rotation and can be loaded with up to 10 kg mass. The radius and period are easily obtained and the force can be observed by the student on the spring scale.

From here, I will just say that variations of these or other demonstrations are left to the imagination of the innovative physics teacher. The demonstrations suggested are very visible to all students even if they do not participate. The sequence of demonstrations described consumes a full class period, but for me, at least, it is one of the most productive 55 minutes of the year.

With regard to safety, the board is rather heavy and due caution should be taken while it and students are in rotation. Keep the exercise serious and do not let the "fun and games" get out of hand.

L. A CORIOLIS SIMULATOR USING A CARBON PAPER TRACE TECHNIQUE

H. Kent Moore

At least four different methods for demonstrating the Coriolis Effect have been described in recent volumes of **The Physics Teacher.** (1-4) I have found another technique which simulates the effect and is relatively easy to set up. It makes use of a carbon-paper trace created by the path of a metal sphere rolling across a rotating horizontal platform. It offers the two advantages of providing a permanent trace record of the sphere's motion relative to the rotating frame of reference and the capability of systematically varying the speeds of either sphere or rotating platform. It should be noted that the sphere, as it rolls across the moving platform, experiences the effects of both friction between itself and the disk surface and rolling angular momentum. For this reason, the motion recorded by the carbon paper trace cannot be regarded as that of a simple particle acting as though under the exclusive influence of the fictitious Coriolis force; the technique, thus, should be looked at as a simulation rather than a direct demonstration of the pure effect.

The apparatus and procedure

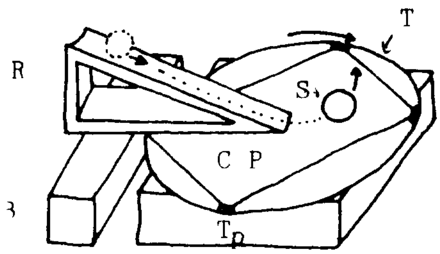


Fig. 3.79. represents a sketch of the basic apparatus. The essential items are: T-Rotating Turntable (variable speed, approximately 30-35 cm in diameter); S-Metal Sphere (approximately 2-3 cm in diameter); R-Grooved Inclined Ramp; B-Ramp Base; C-Carbon Paper; P-Plain Paper; and Tp-Tape.

The metal sphere is released at rest from some point along the ramp incline and thus, as it rolls down to the bottom lip, is "launched" across the level, but rotating, turntable surface. A permanent trace of the sphere's path is recorded on the plain paper in contact with the carbon sheet, both taped to the turntable surface. The launch velocity of the sphere is varied by adjusting the height of its release on the incline.

Results

The apparatus, as described above, lends itself to manipulation of these three parameters: launch position and direction; rate of rotation of the platform; and speed of the sphere at launch.

Figure 3.80 illustrates that when the platform rotates in a clockwise direction, the sphere is deflected leftward in its path regardless of whether lunching direction is from center to edge or the reverse. One may infer that a counterclockwise rotating platform will produce a rightward deflection.

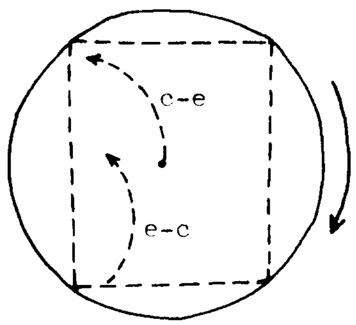


Fig. 3.80. Traces with two launch directions, center-to-edge (c-e) and edge-to-center (e-c).

Figure 3.81 illustrates the comparison between traces when either sphere launch speed or platform rotation speed are varied. Trace I corresponds to a fast launch speed and/or a slow rotation rate while trace II is produced when launch speed is slow and/or rotation rate fast.

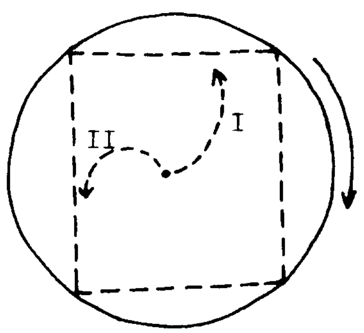


Fig. 3.81. Trace I, launch speed fast and/or rotation rate slow; Trace II, launch speed slow and/or rotation rate fast.

Special considerations regarding apparatus and technique

The turntable surface should be reasonably flat and smooth; plywood or a hard fiberboard of 0.5 cm thickness cut into the desired disk shape is adequate for this purpose. Many physics departments have available a motor-driven rotator to which the platform disk may be mounted. An old and/or inexpensive multispeed phonograph player may also be readily adapted to accommodate the platform; the speed settings found on most players going from 16 to 78 rpm are ideal for affording a suitable range of rotation rates.

The ramp should be securely attached by wood screws or machine bolts to the base in such a manner that the lower lip may extend out as far as the turntable center (as in Figure 3.79); the base should be sufficiently heavy to prevent the ramp's tipping forward. For best results, the ramp should not be inclined at an angle steeper than 20 and should be positioned so that there is as little discontinuity between the lower lip of the ramp and turntable surface as possible; obviously, actual contact between the two must be avoided to permit free rotational movement of the latter. Materials inserted under the base may be used to elevate or lower the ramp to its desired height.

In order to obtain a well defined trace, the metal sphere surface should have a slightly roughened texture. Nonsmudging carbon paper does not leave the darkest trace and therefore is not the most suitable.

I have found that, with some practice, it is usually possible to achieve up to four distinct traces (i.e., four separate launches) on a single piece of paper; however, in order to do so, some attention must be given to the timing of the launch in order to place each trace on an unoccupied sector of the paper.

Instructional considerations

The demonstration described here could well be introduced into a beginning physics course at that point where the topic of vector addition is treated. As a means of stimulating student thinking, it is recommended that before actually launching the sphere and displaying the trace patterns, the students are first asked to conjecture what the direction and relative degree of deflection of the sphere path will be with respect to the rotating platform when variations in launch direction, launch speed, and rotation rate are undertaken. Students are more apt to correctly predict the resulting direction of deflection, right or left, when launch is from center-to-edge in contrast to the edge-to-center case (Figure 3.80). Finally, on the matter of influence by sphere-to-surface frictional effects, the following observations can be made, namely that the sphere's path with respect to the laboratory observer is more nearly a straight line when either the disk's rotational rate is small or launch speed is great. For example, in the case of the edge-to-center launch (e-c in Figure 79) at rotational rates of either 16 or 33 rpm and launch speeds of 120 cms^{-1} or more (inferred from the initial height of release from the ramp), the sphere, when aimed at the disk center, does in fact pass through or near the point; at the same time, the path trace taken on the moving system shows the leftward deflection. However, as rotational rates are increased or launch speeds lessened, the laboratory observer begins to see a correspondingly greater deviation leftward of center.

References

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UNIT 4 LINKED FORCES

I. ACTION AND REACTION? WHAT'S THAT?

Jean Brattin

The next time you're about to introduce your students to Newton's third law, you might enjoy varying the standard lab approach by giving them a problem to which they don't already know the answer. I've tried this over the past four or five years and found it refreshing.

Begin by assuming that they do already know what the law says, and test your assumption by pausing expectantly after, "Newton claimed that for every action ..." Chances are your entire class will parrot the end of the sentence in unanimous chorus.

Now, you ask, what did Newton mean? Let someone propose "an action" and do it, while the rest look for some "reaction" that is not only somehow equal, but - and this is the hard part - opposite. Even those who thought they knew what Newton meant become shaken, since a true reaction to an action by someone who is held in place by gravity and friction is rarely observable.

Having thus introduced a Piagetian disequilibrium into the learning process, you can then promise them an experiment in which the action and reaction will be more obvious. The one I like best is the PSSC lab where a suspended brick drops vertically onto a cart coasting underneath and sticks to it. If you demonstrate it first and ask for what's opposite, eventually someone will come up with the fact that the cart slows down while the brick speeds up in the horizontal plane. Someone else will propose fastening timer tape to the cart so the $\Delta\vec{v}_x$'s can be measured (Figure4.1).

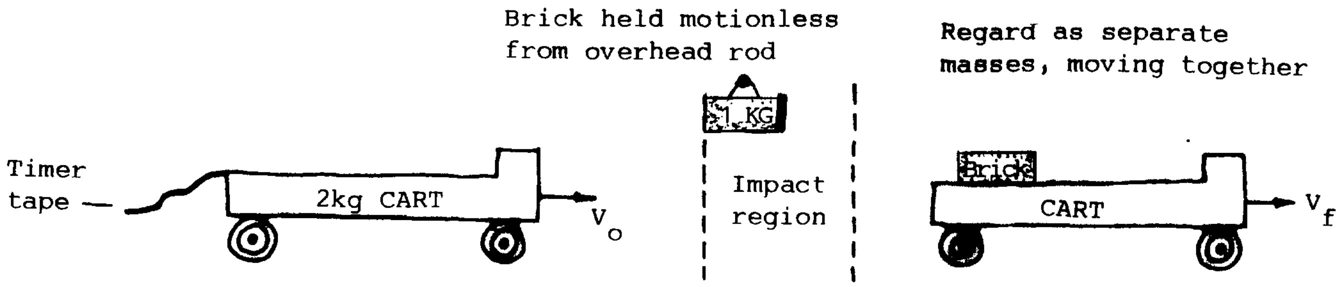


Fig. 4.1.

If they now trudge off to do the lab, confidently expecting to find that $\Delta\vec{v}_{cart}$ is equal but opposite to $\Delta\vec{v}_{brick}$, ah well, you have arranged for a new disequilibrium by ensuring very different masses for cart and brick! (A 2 to 1 ratio works pretty well.)

Although you hope that it will occur to them spontaneously to take mass into account, it usually takes a second experiment to get their attention focused on the relevant variables. A demonstration of two carts exploding apart from rest will do it, if you vary the mass of the one being hit by the expanding spring from as small as possible to as huge as possible. You can show the effect of virtually zero mass by triggering the spring to push against nothing but air. (That gives the cart an interesting little back-forth wobble that you can point out to students later when they're better prepared to understand it.) Letting the spring expand against a wall, of course, represents essentially infinite mass. For in-between mass ratios, if you happen to have rolling stock sturdy enough for people-size physics, it's fun to have a diminutive girl and the burliest boy in the class push each other apart from rest (Figure 4.2).

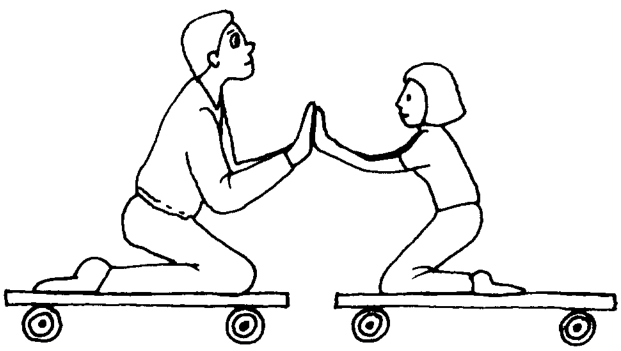


Fig. 4.2.

Incidentally, the cart and brick experiment lends itself to other interesting insights. When students make a "tick-by-tick" velocity-time graph of the impact section of their tapes, they discover that the interaction is not instantaneous. The brick slides and bounces for a fraction of a second (3-15 ticks) before settling down to ride sedately off with the cart. They can actually measure t of the interaction as well as the values of $\Delta\vec{v}_x$ from the graph. This lets them move from an $m\Delta\vec{v}$ to an $m\vec{a}$ and an additional idea of what Newton might have meant by action and reaction.

At this point I like to introduce the new terms, momentum and impulse, and invite students to play around with the definitions and relationships and come up with lots of different but equivalent ways of saying the third law in algebra. (For $m\Delta v$ in the equation $m_A\Delta\vec{v}_A = -m_B\Delta\vec{v}_B$, substitute $m(\Delta\vec{v}/\Delta t)$, ma, F, Δp, $(\Delta\vec{p}/\Delta t)$, $\vec{F}\Delta t$, or $\vec{I}$, for impulse.)

Further insights can spring from this experiment when you ask what kind of forces were acting to slow the cart and speed the brick in the horizontal plane; and what kind of force stopped the brick in its vertical fall, and whatever happened to the vertical momentum it lost? (Horizontally, the force is friction between the surfaces of cart and brick, not increased friction between cart wheels and table, which causes a steady rather than an abrupt change of momentum; and not gravity or the "increased weight and/or mass of the cart" - favorite responses - for obvious reasons.)

I would not like to guarantee that this approach to the third law will blossom into more effective understanding by most of your students. They seem to emerge from any approach still clinging to some cherished misconceptions that will take much longer to dislodge. But you could find it a little more challenging and more fun for your students, and a nice change for you.

II. NEWTON'S THIRD LAW GAME

Section Editor: Earl Zwicker

Here is a dandy way to break the formality of a meeting and get people to loosen up. Marilynn Stone, Schurz High School and Betty Roombos, Gordon Tech High School, both of Chicago, IL, first worked this on our ISPP Group, and they got it from Miller Clarkson, Northeastern Illinois University, Chicago, IL, who was their professor at an earlier time. Try this first between yourself and a friend. Once you've got it down, then introduce it to your group, and have them pair up and go to it all at once. You and your friend face each other standing on the floor. You both raise your arms in front of you and place your hands palm to palm (Figure 4.3). Adjust the distance between you so that both your arms and your friend's arms are extended to about 3/4 their maximum reach. Then you each move your hands back out of contact. Now the object of the game is to make the other person move one or both of his feet from their position on the floor, and this is to be accomplished only by pushing against each other's palms. When you try this, you will soon learn the variety of strategies available to succeed. It is often useful to introduce this game when discussing Newton's third law. Ask: "Is it possible to exert a force on anything without having it push back? Can a single force exist?" The game soon answers this question, and it also clarifies the meaning of inertia as both winners and losers will soon discover!

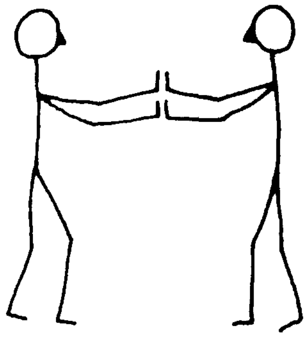


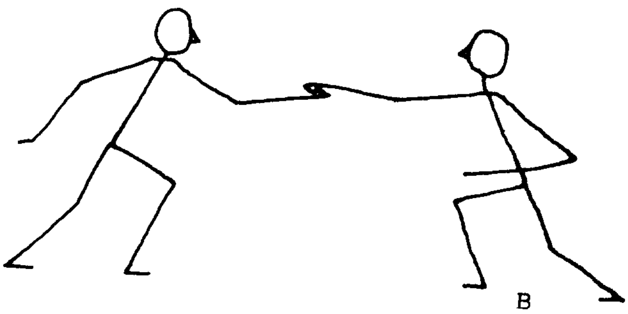
Fig. 4.3. Positions of people to play Newton's third law game.

Why not share your ideas for group activities with everyone? Drop us a line describing something you do.

III. NEWTON'S THIRD LAW OF MOMENTUM AND CONSERVATION OF MOMENTUM

'If I pull you, you pull me; if I push you, you push me'

Try the experiment sketched.

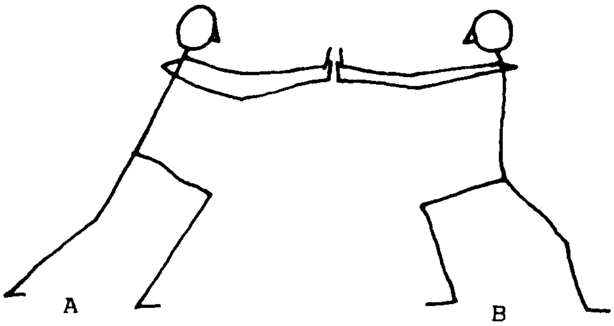


Action = -Reaction The sketch shows one person, A, pulling another, B, with his hand.

Which way is A pulling B, to the left or to the right? Which way is B pulling A?

You cannot have one of those two pulls without the other. But those two pulls do not cancel out and come to no pull at all. B feels only one pull, the pull exerted on him by A. And A feels only one pull, the pull exerted by B.

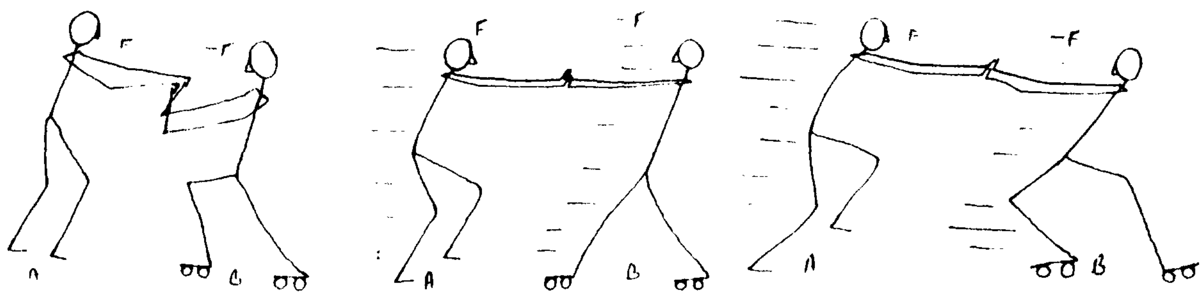
Now look at the sketch of one person,A, **pushing** another person,B.



I push you
you push me
F and -F

The reason why B does not accelerate towards the right when A pushes him is because there is **also** another, quite different, force shoving B, to the left. His rough shoes on the floor stop him moving. The floor pushes him away to the left with a friction-force which just balances the push of A.

If A pushed much harder, friction could not match his push and B would start accelerating to the right.



If B wore roller skates, he would accelerate at once when A pushed him and A would have to run away to the right to keep up that push. Even then, with A and B both running faster and faster A's push on B would still be just matched by B's push on A.

The fact that A pushes B to the right constitutes a force on B. The fact that B pushes A to the left does not constitute a force on B - that is only the force which he is exerting on someone else. So when you are considering B you do not have both forces acting on him, but only the push of A.

Of course if you are considering the combined group A and B together, you should add those two forces making a total of zero.

If A and B stand on a platform on frictionless wheels (or in a boat on water with little friction) it does not matter how strongly they push each other, such pushes will cancel out and not help them to move the platform or boat.

Newton's Third Law We state a general rule: When **any** two objects A and B exert **any** kind of forces on each other the force A exerts on B and the force B exerts on A are **always** equal and opposite.

$$ {}_{A}F_{B} = -{}_{B}F_{A} $$

This is called Newton's Third Law. We use it as a general accounting rule.

IV. a) ACTION-REACTION FORCES IN PULLING A ROPE. I Project Physics

Attach a heavy spring balance to a wall and find two students whose maximum pull is about the same. Then place the spring balance between the two students and have them pull against each other with their maximum force. The balance will read the same in each case. This should help bring home the point that a "pushed or pulled" object, such as a wall, will exert an opposing force whenever a force is applied to it.

b) ACTION-REACTION FORCES IN PULLING A ROPE. II

Place a student on each of two carts and pass a rope between them. First have one student pull alone, then the other, and finally both. Start the carts from the same position each time and note the place where they meet. Ask the class whether an observer, watching the carts alone, could tell which student was actively pulling in each case.

c) REACTION FORCE OF A WALL

When you lean on a wall does it exert a force on you? Stand on a cart or roller skates and lean against the wall.

d) NEWTON'S THIRD LAW

The following simple demonstrations dramatically illustrate Newton's third law. Their simplicity, moreover, gives some indication of the elegance and profundity of this remarkable law.

To show that forces exist in pairs on different objects, and that the paired forces act in opposite directions, set up a linear equal-mass explosion between two dynamics carts. Propel the carts apart with a steel hoop, magnets, streams of water, or any other forces you can think of. See Figure 4.4 for some suggestions. Stress that this concept of force-opposite-force is valid for all types of forces.

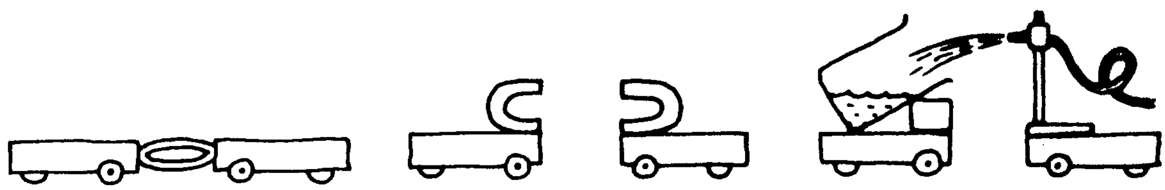


Fig. 4.4.

The experiment on conservation of momentum, E3-1, gives detailed instructions about the explosion using the steel hoop. You can take a strobe photograph of the explosion, and show that if the carts have equal masses, they move apart at equal speeds. If the carts have equal speeds, the accelerations they received during the explosion were equal in magnitude. Since the carts have equal masses and since the duration of the interaction is the same for each cart, Newton's second law implies that they experienced equal forces during the explosion.

A more direct method to show that the forces are equal in magnitude is to modify the demonstration by propelling the two dynamics carts with large magnetron magnets. Move the magnets back about 3 cm on the carts. Place a pencil or dowel in the hole at the front of each cart and loop an 8 cm rubber band around the pencils. When you release the carts, they will separate, stretch the rubber band, oscillate, and finally come to rest.

When the carts are at rest, the forces acting on each cart are those shown in Figure 4.5. The tension in a rubber band is uniform, so T = T'. Since each cart is at rest, then T = F and T' = F'. Thus F = F', and the magnetic forces on the carts are equal. Note that in this demonstration the carts can have different masses.

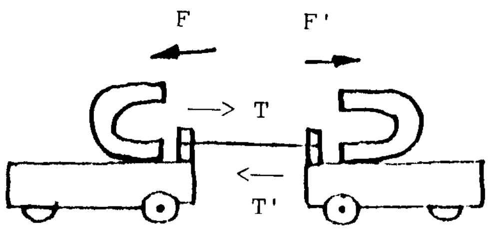


Fig. 4.5.

Another exciting way to illustrate Newton's third law is to mount a sail on the fan cart that was used to illustrate uniform acceleration D4, and let the propeller blow against the sail. Since the sail bends forward, clearly there is a force on it. But the cart does not move because when the propeller pushes against the air, the air exerts a reaction force against the propeller. Thus, the net force on the glider is zero. (If the sail does not catch all the air from the propeller, the cart may move slightly.) If you remove the sail, the only force on the glider is the reaction force exerted by the air on the propeller. This force causes the glider to move backwards.

The fan cart rigged for uniform acceleration is sketched in Figure 4.6. The placement of the sail to show action and reaction is sketched in Figure 4.7.

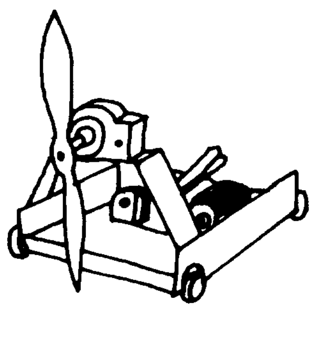


Fig. 4.6.

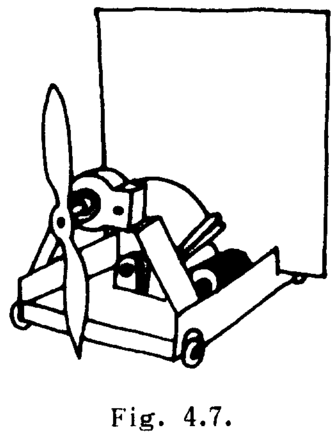


Fig. 4.7.

e) ACTION-REACTION FORCES BETWEEN CAR AND ROAD

Demonstration of the coupling of forces between a car and the road. Obtain a motorized toy car. Place a piece of cardboard on top of some plastic beads or an upside-down skate-wheel cart. Then place the wound-up car on the cardboard roadway. The opposing forces will cause the roadway to move backward when the car moves forward.

f) ACTION-REACTION FORCES IN HAMMERING A NAIL

Hammer a nail into a plank while the plank is first on a bench, then on a soft pillow. The force exerted on the nail depends not only on the hammer but also on the opposing force of the plank.

g) ACTION-REACTION FORCES IN JUMPING UPWARD

When you jump off the floor, does the floor push harder on you in order to cause the upward acceleration? Jump up from a bathroom scale and watch the scale.

V. A QUICK DEMONSTRATION OF NEWTON'S THIRD LAW

Virgina F. Walters and David D. Dreyfuss

With an air track, one can devise a very simple but effective demonstration of Newton's third law (preparation time: five minutes).

Take a small air track glider, a plastic ruler with a groove down the center (the kind used in the PSSC experiment "Collision in Two Dimensions"), appropriate shims, tape, or whatever is lying around. Attach the ruler so that it becomes an inclined slope on top of the glider with a stop at the lower end. When the glider is on the air track, roll a ball down the groove: the glider will start and stop most satisfactorily as the ball starts and stops.
This demonstration may lead to fruitful discussion of conservation of momentum, vectorial property of momentum, and conservation of energy.

VI. AN EASY DEMONSTRATION OF NEWTON'S THIRD LAW

Adolf Cortel and Luis Fernandez

The assembly described here allows a quick and rather exact demonstration of Newton's third law, in a static situation using forces between two magnets, and without any dependence on the principle of conservation of the momentum. Thus, this experiment can be very useful for a clear understanding of different situations, like those in which gravitatory forces are involved, that put severe problems to students.

The demonstration is performed calculating the reciprocal repulsion forces between two magnets suspended from the same point, by the reading of its separation taken against a vertical sheet of millimetered paper.
A convenient permanent assembly is described as follows:

Two hanging magnets with different mass (m_1 and m_2) and a different geometric shape (1), are placed with the same poles facing to each other (by a thread tied to an elastic band which encircles the magnet, stuck as shown in Figure 4.8, by means of two pieces of adhesive tape). Both threads are placed into the slots of two screws A and B (Figure 4.9) with both magnets hanging free of friction in front of a millimetered sheet P, stuck on a rectangular piece of wood F set vertically on a second piece of wood G placed horizontally by bolts and their nuts. This allows the levelling of the assembly after obtaining perfect vertically lines on the millimetered sheet (any of the two magnets may act as a plumb). The length of the thread is such to place the centre of mass of each magnet on the same horizontal. Screw C tightens the washers V and V' between which the two threads are placed, thus allowing to adjust their length.

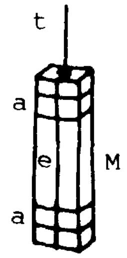


Fig. 4.8. M magnet, e elastic band, a adhesive tape, t thread.

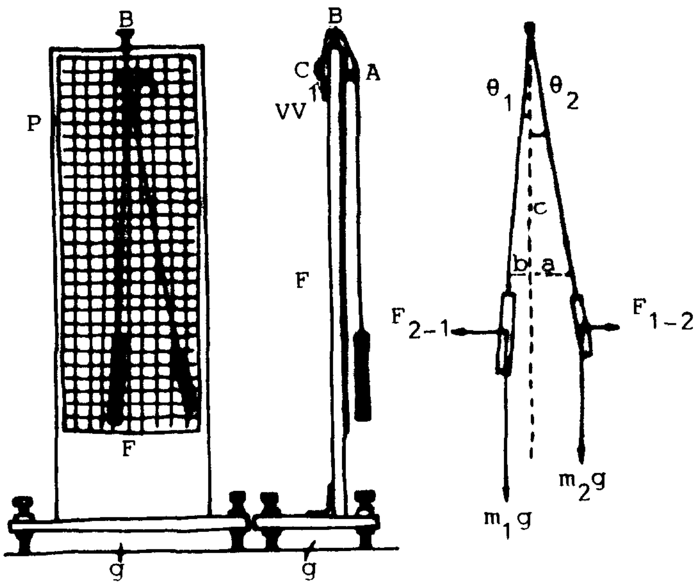


Fig. 4.9. A, B and C screw, V and V' washers, G and F pieces of wood, P sheet of millimetered paper.

As shown, the repulsion forces of the magnets are:

$$F_{2-1} = m_1 g \tan\theta_1 = m_1 g b/c$$

$$F_{1-2} = m_2 g \tan\theta_2 = m_2 g a/c$$

Known m_1 and m_2, the measure of segments a, b and c by means of the millimetered sheet (2) makes it possible to calculate both forces and compare the results obtained. If the length of the threads is between 20-40 cm, the values of the reciprocal forces differ in less than 3 per cent. Better results are achieved increasing the length of the threads, but that is obviously limited by the size of the supporting frame.

References

1. To perform this experience we have used two magnets Superalnico of 68.5 (prismatic) and 42.5 g (cylindrical).
2. To avoid the error of parallax when parameters a and b are measured it may be useful to stick a strip of reflecting plastic sheet on the millimetered paper.

VII. A FRICTIONLESS ACTION-REACTION WHEEL USING AN AIR TABLE

R.L. Wild & R.A. Morandi

A convincing action-reaction lecture demonstration can be constructed using a toy train on a pivoted track. The usual track must have an elaborate central bearing if it is to approximate a frictionless situation. Most demonstration devices constructed to date fall far short of this requirement.

We have built an inexpensive rotating platform utilizing an Ealing-Daw air table(1) which has proved to be frictionless and highly satisfactory. The picture (Figure 4.10) shows most of the essential features of the device. A 1 m circle of 2.5 cm thick styrofoam(2) with a small air bearing in the center, forms the base for the frictionless track system. Black stripes on the circle help show rotation. Any painting of the styrofoam must use water base paints. The brass air bearing (see Figure 4.11) screws into the bottom of the air table in an existing 1/4 x 20 tapped hole, and is fed by a separate air hose. The track system floats on the air cushion of the table. An HO toy train and track completes the device. The locomotive and the two cars, weighted so all three have equal mass ($\approx$ 300 g), are positioned symmetrically by three 3 mm aluminium rods which are bent on the ends and fit into aluminium sockets fastened on the ends of the cars. The train cord is simply suspended from a rod, approximately 1 m above the center of the table. This arrangement keeps all mass symmetric so that the track rotates smoothly.

The frictionless condition allows the system to be used to demonstrate conservation of momentum as well as action-reaction. The following sequence illustrates the versatility of the arrangement. (The air bearing stays turned on for all demonstrations.)

1. Air table off: Start and stop train to establish normal "expected" behavior.
2. Air table on: Start the train and demonstrate opposite rotations of

train and track. Turn off the train switch and both train and track stop.

3. Air table off: Start the train and when terminal velocity is reached, turn the air table on - the track does not rotate. Stop the train and the track system gets the angular momentum. Restart the train and the track stops again.
4. Air table on: Turn the locomotive on and hold it by hand until the track acquires terminal velocity. Release the train and it will remain stationary in the lecture room coordinates until you turn off the air table.

The major expense involved (for those already possessing an air table) is the HO train and power pack. The remainder can be built in a student shop. This is a most convincing lecture demonstration.

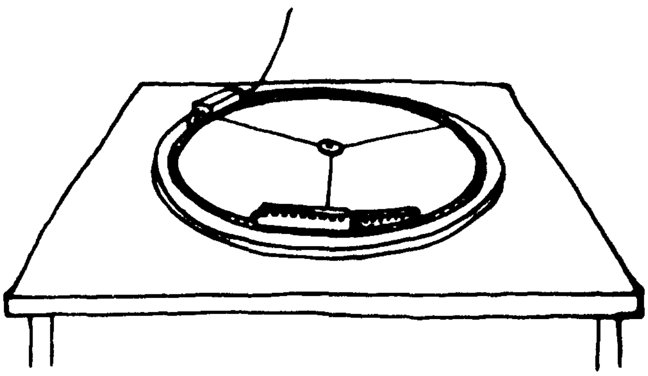


Fig. 4.10. A frictionless action-reaction system using an air table.

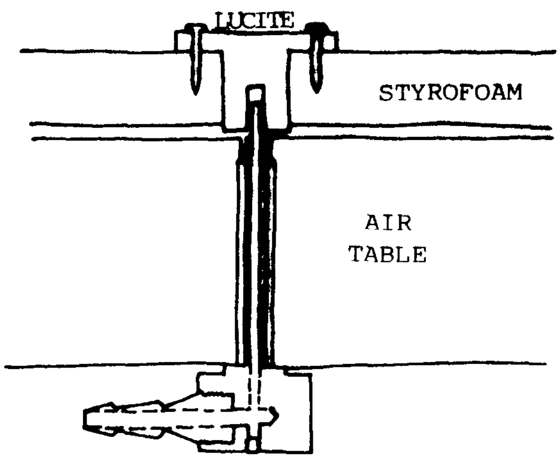


Fig. 4.11. Detail of the central air bearing.

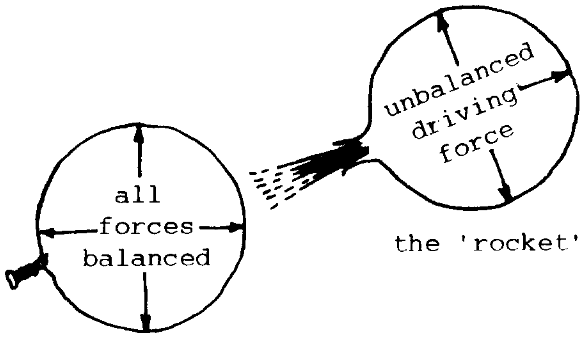
We would like to thank Mr. John Pollock for assistance in constructing the track assembly and air bearing.

(1) Ealing part number CB34-0000.
(2) Made by Dow Chemical Co., Midland, Michigan 48640. Usually available locally at lumber yards or hobby shops.

VIII. INDOOR ROCKETRY THAT JUNIORS CAN UNDERSTAND Alan Ward

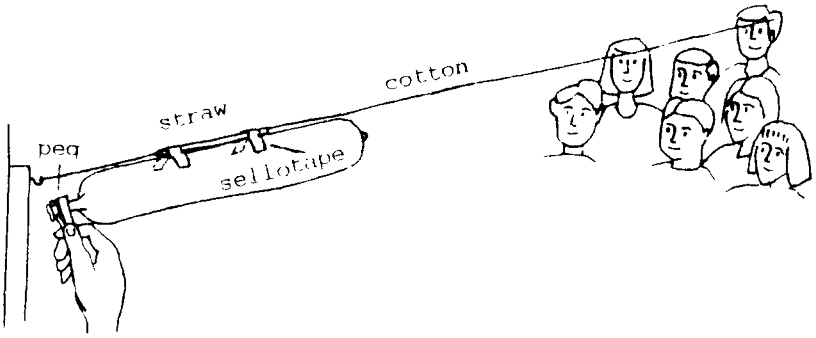
The most familiar examples of Newton's law that 'every action has an equal and opposite reaction' are the jet engine and the rocket motor, yet, personally, I have always found these more difficult to imagine than - for instance - the idea that it is the reaction of the firm ground to the downward action of my foot which supports and propels my walking. I suppose the reason for this difficulty is that, with jets and rockets, I am too distracted by the impressive surges of the exhaust gases, and therefore I find it difficult to concentrate on how the gases inside the devices are pushing 'forward' on them. Of course the example of the rocket is different from walking. The action of the gases pressing forward on the vehicle drives it, and the awesome effulgence that misdirects my attention is the reaction. I am well aware that what I have just said is the reversal of what textbooks generally say, but does it matter if action and reaction are equal as well as opposite? It also occurs to me that I may have stumbled on the reason why so many people believe that it is the gases pressing against the surrounding air that drives a rocket: a misconception, belied by space travel, which teachers are quick to dispel, without much corrective clarification.

These abstractions mean little to most primary school teachers, many of whom may be called upon to help juniors to understand how jet and rocket propulsion work. I would advise them to put aside what they may know about Newton's third law of motion - and to consider the simple explanation of why a toy balloon whizzes about, when inflated and then let go. Older juniors can appreciate that the air inside a blown up balloon is under pressure and being forced against the inside of the balloon envelope. (The energy in our 'balloon rocket' is stored in the 'spring' of compressed air, and in the tense 'stretch' of the balloon skin.) A diagram of a static balloon - with its neck shown sealed - can be used to show very clearly how all forces acting on any part of the inside of the balloon must be balanced by equal forces acting the other way. A second diagram can be drawn, to show what happens when air is allowed to escape, after the neck is opened. Obviously the unbalanced internal force, acting on the inside 'front' of the balloon, must be the driving force. In my experience juniors can understand this idea.



static balloon

When, during my Science Happening on 'Falling and Flying', I have discussed the balloon model with juniors, I am ready to stage a rocket launching as a finale. The twofold aim of my demonstration is to reinforce the explanation through some fun and excitement, whilst giving the attending class teachers a basic device for extending the science



work afterwards. My 'rocket' is a sausage balloon that I inflate by using a cardboard balloon pump. The balloon is then sealed with a clothes' peg and put aside. Next I draw everybody's attention to a cotton line that I have previously fixed to a high point in the hall at some distance from my table. I bring the line - ideally over the heads of the children - towards my centre of operations, where I use its end to thread a large darning needle. Cutting a paper drinking straw in half, I then thread half the straw on to the line, discard the needle, and tie the end of the cotton to my table. Then, when the line is tight, I have a child help me to fix the balloon underneath the straw, using two short strips of Sellotape. I make sure that the straw is over the top middle part of the balloon, and that the balloon and straw are in line. I undo the peg and grip the balloon neck - waiting ... The children need little encouragement to begin counting down: 5, 4, 3, 2, 1, Fire! As the rocket balloon shoots up the line, the children react with happiness, wonder and a pleasing tumult of applause. And we can do encores...

IX. A 'GRAVITY MOTOR' DRIVES A JET BOAT — Alan Ward

(- - -)

Water standing in a plastic cream pot is forced by gravity to push outwards. Opposite pressures on all parts are balanced, so the pot does not tend to move in response to these components of the force. But if there is a hole in the side, water jets out, leaving some unbalanced force pushing the other way. But friction stops the pot being driven sideways by this gravity motor effect. **Can it be made to propel itself?**

Reduce friction by floating the pot on water. Do this after standing the pot in the middle of a polystyrene meat-tray 'boat'. A 0.7 cm diameter plastic tube is run from the hole near the bottom of the pot, and out through the little vessel's stern. Holes are bored with a warmed cork-borer - and, for the sake of elegant handling, the end of the protruding 'jet' tube is corked. See Figure 4.12.

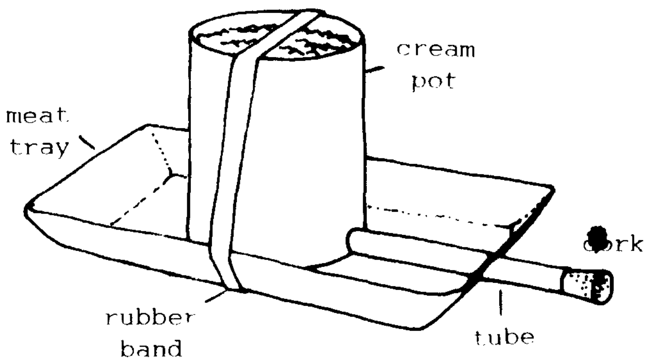


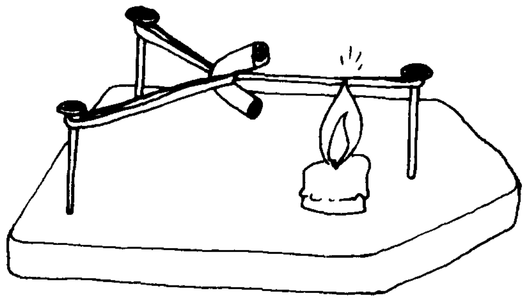
Fig. 4.12.

A rubber band holds the gravity engine tightly amidships. Now we are ready for testing. Fill the 'water-tank', and launch the boat at one end of a bath, or large sink. Remove the cork. Then, for seconds the boat accelerates, after which it glides, by declining momentum, to the far end of the bath. Juniors will not be alone in appreciating gravity motor jet boat races held across a small pond.

X. A MODEL ROCKET TO DEMONSTRATE NEWTON'S THIRD LAW OF MOTION

Randle Hurley

This extremely cheap model 'rocket' is both quick and easy to make. It can be used to demonstrate Newton's third law and, with a little ingenuity, can be used to provide data for momentum calculations.



The rocket is cut from 1 cm thick wood. A light rubber band is attached to the two nails in the stern; the size should be chosen such that the band is under slight tension. The rubber band is tied back in the position shown by a loop of light string. A pellet of paper is placed on the band and the stub of candle is placed off centre as shown. The rocket is now ready to be placed in the water. As large a trough as possible should be filled to a depth of about 2 cm. The candle may be lit once the surface and the rocket are still and the rocket is pointing along the longest stretch of water. The candle is placed off centre so that the string does not burn through too quickly.

When the string burns through, the pellet is ejected and the rocket moves slowly forward. Resetting the rocket without a pellet and refiring shows that no movement results when there is nothing to throw away. The string should be wound round the bow pin a couple of times to prevent the string from being thrown off and thus upsetting the calculations.

The following experiments should get more mileage out of the rocket:

1. Weigh the pellet and the rocket, fire the pellet and measure the speed of the rocket. The speed of the pellet may be estimated using the data.

2. Repeat the experiment with a heavier pellet and then compare the speeds observed with the results of another pair of experiments in which the same two pellets are fired with a stronger elastic band. This data may be used as the focus for a discussion on the nature of momentum.

XI. DEMONSTRATING A 'SOLAR CANNON'

Alan Ward

According to a news item in the **Daily Telegraph**, 'the average energy from the sun falling on a square metre of British soil throughout the year is about 50 watts.' It reminded me of an anecdote in that wonderful old textbook **Nature's Mystic Movements** (Pitman, 1933) by imaginative A.T. McDougall. He mentioned a gentleman who was killed instantly by a shot from a flint-lock pistol, the trigger of which was not pulled. It was neither murder nor suicide. Examination of the room showed that a water-filled goldfish bowl had acted as a lens, focusing the sun's rays on to the pistol's flashpan. Intense heat ignited the gunpowder and discharged the loaded weapon.

In any discussion of how solar energy might be harnessed, children will be fascinated by this bizarre accident. Indeed, I believe the story inspired a 'perfect crime' plotted during a 'Molecule Club' dramatization of scientific principles at London's Mermaid Theatre. Also, a recent photograph in the **Observer** colour magazine showed a solar alarm clock, which was a combination of sundial and a lens pre-focused to discharge a little brass cannon.

These ideas can be illustrated with the aid of a 'flat' 4-ounce medicine bottle, a cork, four red-topped matches, some pencils, and a magnifying glass. The object is to improvise a 'solar cannon'. Wedge the close-packed tail ends of the matches into a hole in the narrow end of the cork. Fix the cork - **not too tightly** - into the bottle. Then set the bottle upon the pencils, which are to serve as rollers. Do this on a bench top in strong sunlight. **Of course safety must be attended to, so observers can be placed behind a transparent screen.**

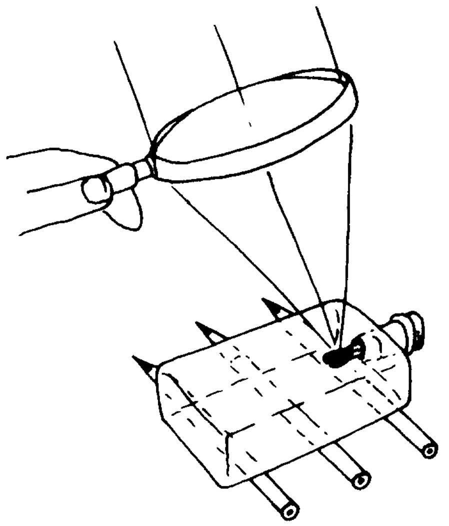


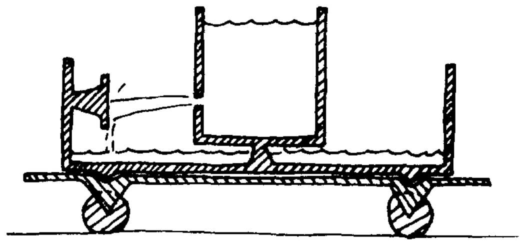
Fig. 4.13.

Use the magnifying glass to focus solar radiation through the bottle glass, on to the matches. Eventually a match smoulders, before suddenly bursting into flame, and setting fire to the other matches. The pressure of evolved gases ejects the cork like a bullet - and, at the same instant, the force of reaction drives the bottle gun back on its 'carriage' of rollers.

XII. A SELF-PROPELLING MECHANISM Lewis Epstein

We are all familiar with mechanisms proported to violate the first law of thermodynamics, and some of us have even made acquaintances with mechanisms proported to violate the second law of thermodynamics, but have you ever met one which proports to violate Newton's first or second law? The mechanism about to be described is intended to accelerate without the application of external force or the ejection and loss of reaction mass. The mechanism does require energy to operate.

A sled or railroad mounted prototype of the mechanism will be outlined; however, its immediate adaptation to space craft is apparent. The machanism is truly the essence of simplicity. (Perhaps this is why it has not been previously noticed.) It consists of a water bucket with a hole punched in its side close to the bottom. The jet of water squirting from the hole impinges on a splash plate and then falls into a collecting basin. If desired, the cycle can be closed by a pump that lifts the water from the basin back into the bucket.



Schematic of self-propelling mechanism.

Since the prototype is railroad mounted, only horizontal forces are of concern. Were the bucket not punctured, there would be no net horizontal force on it, since the horizontal pressure exerted by the water at any point on its side would be nullified by an equal but counter-directed pressure on the opposite side of the bucket. Punching a hole in the bucket upsets this balance. If a hole of effective area **A** is opened at a depth where the water pressure is **P**, the balance is upset by an amount **PA**, representing a net force F_b pushing on the inside of the bucket opposite the hole. So we have an elementary rocket.

Now we must consider the force, F_s, of the jet impinging on the splash plate. Off hand F_s would be expected to counteract the reaction force, F_b = PA, on the bucket. Let us see. In accordance with Torricelli, if energy is to be conserved, the velocity, v, of the water squirting from the hole must equal the velocity that a body would obtain when falling freely from the height, **h**, of the water surface to the hole. Whence:

$$1/2v^2 = gh$$

Now, if the water has density, ρ , its pressure at the depth where the hole was punched must be:

$$P = \rho gh$$

and thus:

$$P = \rho\ 1/2v^2$$

or:

$$F_b = \rho\ 1/2v^2.A.$$

The counter force against the splash plate must be the time rate of change of the water jet's momentum as it strikes the plate. To make things simple, the plate is covered with a screen, so the water will not rebound. The plate then simply absorbs the momentum in the jet. The mass of water impinging on the plate during a time, t, must be ρ **vAt** and its momentum must be ρ **v²At.** The time rate of change of this momentum is ρ v^2A and accordingly the force against the splash plate is:

$$F_s = \rho\ v^2A.$$

So it turns out that:

$$F_s = 2F_t.$$

The force on the splash plate does not just counteract the reaction force on the bucket, it overwhelms it by a factor of two, and we must conclude there is a net force on the whole mechanism. The mechanism is compelled to accelerate in the direction of the splash plate.

What consequences this may foreshadow for interplanetary travel cannot be known. What consequences this may have on a prelim examination are even more foreboding.

XIII. THE BOUNCING DART

Paul G. Hewitt

When demonstrating momentum conservation with the air track it is neat to show that when a small low-mass glider is bounced from a more massive stationary glider, the velocity imparted to the more massive glider is visibly greater than it is when Velcro is used and the collision is inelastic. In showing this we can explain that the impulse is greater for bouncing because the more massive glider not only supplies the necessary impulse to stop the low- mass glider, but provides even more impulse to stop the low-mass glider, but provides even more impulse to set it moving in the opposite direction. Depending on the elasticity and mass ratio involved, this results in up to twice the impulse and up to twice the momentum imparted to the more massive glider when bouncing occurs as compared to sticking when Velcro is employed.

I follow the standard air-track demonstration with a simple demonstration that more clearly shows the greater impulse associated with elastic collisions. I call the demonstration the **bouncing dart.** The dart I use is fashioned from a stubby wooden furniture leg with plastic fins stuck in slots cut on one end, and a rubber plumbing gasket glued to the other end. A sharp nail with its head cut off fits into a hole centered in the middle of the gasket. Following the suggestion of my friend Dave Wall, I launch the dart by suspending it from a length of string to make a simple pendulum which is allowed to swing against the upright block. The amplitude of swing for not quite knocking the block over with the nail-nosed dart is established and a marker appropriately positioned so your class can see that you raise the dart by the same amount each time you allow it to swing into and collide with the block. When the nail is in place the collision is inelastic and the dart thuds to a stop. The blow is not enough to knock the block over. When you repeat the procedure with the nail removed, the rubber-nosed dart bounces from the block which is clearly knocked over (Figure4.14).

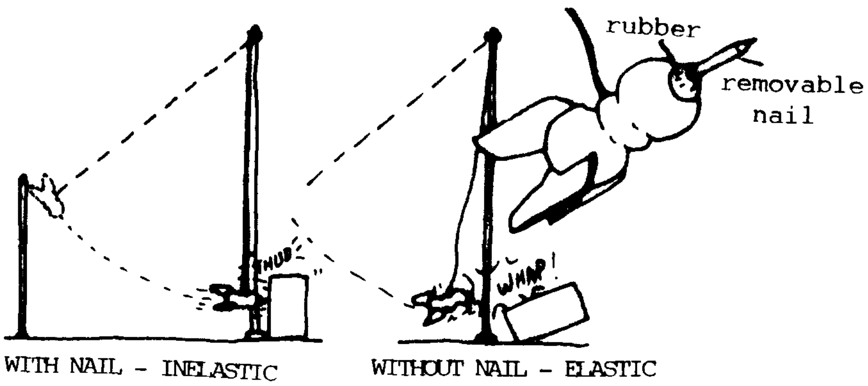


Fig. 4.14.

You can follow this demonstration by citing the invention of the Pelton wheel back in the gold-rush days in California. Lester A. Pelton made a fortune, not by finding gold, but by patenting the design of cup-shaped turbine blades which effectively cause incident water or steam to bounce from the blades of a turbine and make a U-turn. In this way up to twice the momentum is imparted to the turbine by the moving fluid.

XIV. AN EXPLOSIVE PENDULUM TO SHOW CONSERVATION OF MOMENTUM

Marvin Ohriner

In attempting to show quantitatively how momentum must be conserved, I devised the following inexpensive and easily constructed device which resembles a ballistics pendulum. The modifications suggest calling it an "explosive" pendulum. Two blocks of wood (whose masses are previously determined) are each supported from the chalk board top rail by two strings and tied together with thread so as to compress a spring between them. When the thread is burned, the two blocks swing apart as shown in Figure 4.15 and rise to heights h_1 and h_2 respectively. These heights are obtained by having two students each mark the point of the maximum height of the blocks on the chalk board as the blocks swing up.

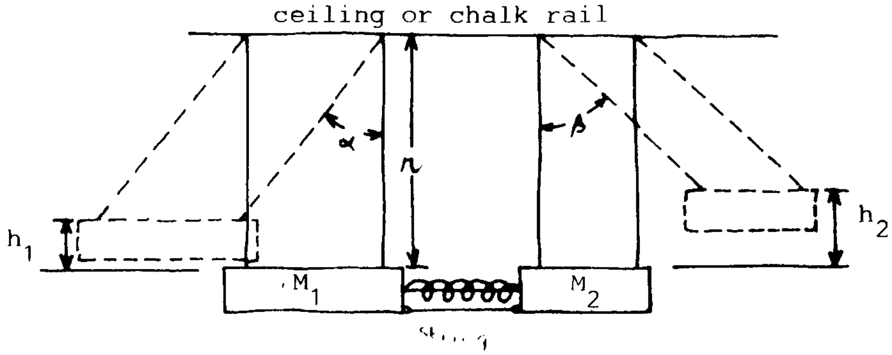


Fig. 4.15.

The potential energy gained by each block can now be found: $PE_1 = m_1gh_1$ and $PE_2 = m_2gh_2$. Since this is an essentially frictionless pendulum, we know the kinetic energy of each block immediately after the "explosion" was equal to the increase of its potential energy at the peak of its swing. Hence: $(1/2)m_1v_1^2 = m_1gh_1$ and $(1/2)m_2v_2^2 = m_2gh_2$. Since m_1, m_2, h_1, h_2, g are known, we can solve for v_1 and v_2. We can then check to see if $m_1v_1 + m_2v_2 = 0$ after the explosion as it obviously was before the explosion. Within the limits of error in our measurements we found that momentum is conserved, that is $m_1/m_2 = v_2/v_1$.

Some details of the arrangement follow. The larger block m_1 is fitted with a headless nail as a guide for the spring (Figure 4.16). The smaller block is drilled to receive this nail when the blocks are forced together to compress the spring. A further refinement to ease the operation consists of a U-shaped wire link fitted into a hole in the top of each block (Figure 4.16) to hold the blocks compressed in place temporarily while the thread is tied around the blocks. The U link is then removed and the thread burned to release the blocks and cause them to swing up.

Rather than measure h_1 and h_2 directly, I found it preferable to measure the angle α and angle β (Figure 4.15) and the distance r from the point of suspension to the upper surface of the blocks. From trigonometry we have:

$$h_1 = r(1-\cos\alpha) \qquad h_2 = r(1-\cos\beta)$$

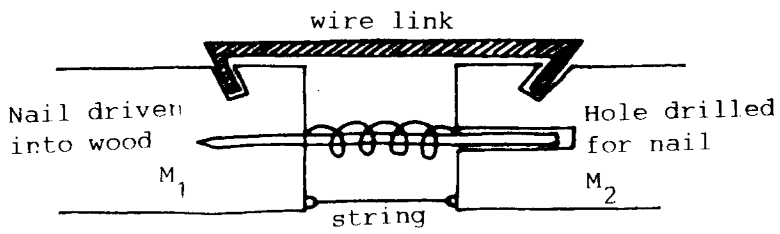


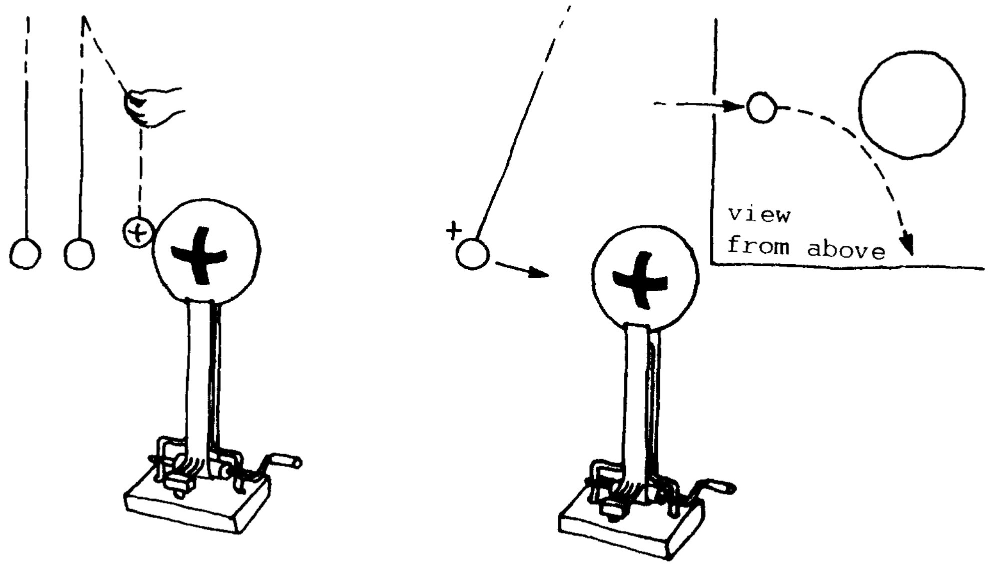
Fig. 4.16.

In addition to considering momentum in this presentation, the problems of kinetic energy and potential energy are also involved and interrelated in the finding of the solution and hence make for an interesting experiment or demonstration.

XV. COLLISIONS CONTROLLED BY ELECTRIC CHARGES Nuffield O-Level Year 4

Run a Van de Graaff machine until the large ball has a large electric charge. Hang a table-tennis ball (coated to make it conducting) near the large ball, on a long nylon thread. Charge the small ball, by letting it touch the big one. Pull it to one side and throw it towards the big ball. Watch its motion.

This is a good model of a nuclear collision. The large ball might represent the nucleus of an atom of gold in a thin sheet of gold leaf. The small ball might represent a high-speed alpha- particle from some radioactive atom.



XVI. THE CONSERVATION OF LINEAR MOMENTUM IN TWO DIMENSIONS (WITHOUT AN AIR TABLE) John Marshall

Introduction

The following experiment seems to give a lot of satisfaction to students, costs very little, and can be used with quite large sets.

Preliminary

The velocity v of the bob of a simple pendulum at its mid-point is directly proportional to the amplitude of the oscillation.

Proof

See Figure 4.17. From the principle of conservation of energy:

$$1/2mv^2 = mgh$$

Now	$h(2l - h) = r^2$	
or	$2hl = r^2$	very approximately
Hence	$mgh = mgr^2/2l$	
or	$1/2mv^2 = mgr^2/2l$	

$$v = r\sqrt{g/l}$$

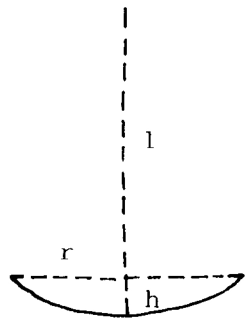


Fig. 4.17.

Equipment

Two small blobs of Blu-tack (1) are stuck on the ends of equal lengths of very light thread which are hung from the same point of support in the ceiling of the lab. Their lengths are adjusted so that they both just clear the surface of a drawing board on the bench beneath (Figure 4.18). On this drawing board a series of concentric circles are marked on a big sheet of paper, using increments of perhaps 3cm from one radius to the next. The diagram is labelled 'Impact Velocity Diagram' and successive circles are marked $v = x$, $v = 2x$, $v = 3x$, etc. The local constant $x(= \sqrt{(g/l)})$ may be calculated and marked in at the foot of the page if desired, but this is not essential.

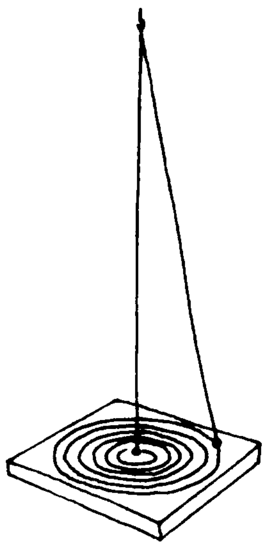


Fig. 4.18.

Experiments

1. The masses are made equal. One pendulum, A, is hung stationary at the centre and the other, B, is pulled out to the circle $v = 6x$, then

released. The two pendulums stick together on impact (the reason of course for the choice of Blu-tack) and swing together to the circle v = 3x. Similar checks may be made with different impact velocities.

2. Pendulum A now has half the mass of pendulum B. After collision the combined masses swing to the circle v = 4x.

3. Now things begin to catch fire. In my experience students take a delight in carrying out further collision experiments, and predicting the outcome by placing a mounted pin under the point where the combined masses will come to rest momentarily.

4. On now to the two-dimensional situation. The pendulum are again made of equal mass for simplicity and are pulled out to the v = 6x circle in directions at right angles to one another, say North and East. It is not easy to release them exactly simultaneously and a fine thread linked to both round the back of two retort stands can be used. This thread is broken by burning with a match.

Once the idea of adding momenta by the parallelogram law has been established, one can try equal masses, and equal velocities (v = 6x), but directions making an angle of 120° with one another for another simple prediction. It is about now that one runs out of time, but quicker students can investigate the condition required for one mass to deflect the other (of half its mass) through 90°. They may need the hint that for a given starting point for the light pendulum, the heavy one must start at some point on a straight line across the diagram ... why?

Reference

1. Bostick Blu-tack, manufactured by Bostick Ltd, Consumer Products Division, Leicester.

XVII. CONSERVATION OF MOMENTUM - WALKING THE BOAT

Akio Saitoh

Many texts contain problems similar to the following: A man of mass 60 kg is standing on a flat boat at a point 10 m from shore. He walks 2.4 m relative to the boat toward shore and then stops. If the mass of the boat is 300 kg and it is assumed there is no friction between the boat and the water, how far is the man from shore when he stops?

Conservation of momentum predicts that the center of mass of the boat-man system does not move. Application of this concept predicts that, while the man walked 2.4 m on the boat, the boat moved away from shore 0.4 m and the man is now 8 m from shore.

The apparatus described here allows checking the above calculation in the student laboratory. Construction cost is low and the results agree well with theory.

Figure 4.19 shows a runway made of acrylic sheet which can roll freely over another acrylic plate separated from it by many steel ball bearings 0.475 cm in diameter, which greatly reduce any fricnition. The lower plate must be carefully leveled.

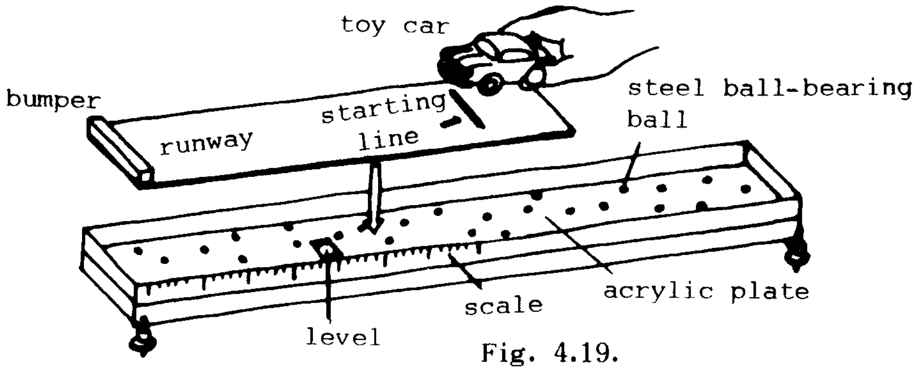


Fig. 4.19.

A spring-wound toy car placed at one end of the runway is released and the car and runway begin to move in opposite directions. When the car strikes a bumper at the end, both car and runway stop simultaneously. The ratio of the distances moved by car and runway as well as their respective velocities, relative to the fixed lower plate, are in the inverse ratio of their masses.

Using this apparatus, the two experiments shown in Figure 4.20 were performed. In Figure 4.20a, the car has a mass of 90 g and moves 24 cm while the runway has a mass of 180 g and should move 12 cm in the opposite direction. In Figure 4.20b, the mass of car and runway are 180 g each and each should move 18 cm. Experimental results were in good agreement with these predictions.

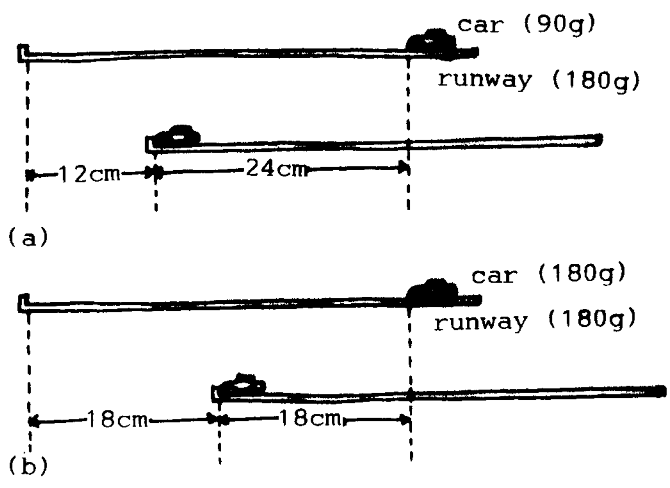


Fig. 4.20 (a) The car moves 24 cm, and the runway moves 12 cm.
(b) Both car and runway move the same distance, 18 cm.

XVIII. KARATE DEMONSTRATION

George A. Amann and Floyd T. Holt

Demonstrating the large forces that may be generated by a rapid change in momentum in a manner that is both visually stimulating and possible for the students to try safely themselves, is often difficult. While searching for a method to emphasize the magnitude of these forces, we happened to see the excellent article on karate in the April 1979 issue of **Scientific American**, by Michael Feld, Ronald McNair, and Stephen Wilk.(1) After reading their careful analysis of the forces acting and the energy required to break objects with a karate blow, we decided to try to apply this as a demonstration during our discussions of the law of impulse-change in momentum. The purpose of this note will not be to give a detailed analysis of the physics of a karate blow, but to indicate how this can be successfully incorporated in your lesson as an exciting, student-centered demonstration.

To try out our ideas, we purchased several long pieces of 30 cm wide pine board (nominal thickness 2 cm), from our local lumber yard. After cutting the boards to approximately 30 cm lengths, we attempted to split them by striking them with our hands in the center of the wide face, parallel to the grain. We found that this was easily accomplished when the ends were held up by two adjacent desks, and the boards were hit with a closed fist swung down over our heads in the classic "hammer strike" fashion.

Encouraged by our success, we had a few students (both boys and girls) try it. None of them had any difficulty breaking the boards. Furthermore, their enthusiasm for this activity very quickly exhausted our supply of material.

In discussions with our students we chose a much simplified analysis employing the impulse-momentum equation to give an approximate value for the forces that are available to break these boards.

Using the mass of a student's hand to be 0.6 kg, and its velocity during the downward strike to be 10 ms^{-1} (obtained by strobe photography), the hand's momentum is given by

$$p = mv = (0.6\ kg)\ (10\ ms^{-1})$$
$$p = 6\ kgms^{-1}$$

When this momentum is delivered to the board, the maximum time available to stop the fist is determined by the thickness of the board, and the amount it flexes. Assigning the values of 2 cm and 1 cm respectively for these values, we get a maximum stopping time available given by

$$t = s/\bar{v} \qquad \text{where } \bar{v} = (v_i + v_p)/2$$
$$\bar{v} = (10\ ms^{-1} + 0)/2 = 5\ ms^{-1}$$

$$t = (0.030\ m)/(5\ ms^{-1})$$
$$t = 6 \times 10^{-3}\ s$$

Using the impulse momentum equation yields a minimum force

$$F\Delta t = \Delta(mv)$$
$$F(6 \times 10^{-3}\ s) = (6\ kgms^{-1}) - 0$$
$$F = 1000\ N$$

For students interested in a more detailed description of the operative physics, we refer back to the **Scientific American** article.

This demonstration may be extended to breaking more than one piece of lumber by placing pencils between successive layers of wood, and then proceeding as before.

While performing this demonstration, you may wish to wear a leather work glove to prevent any difficulty with wood splinters, and we suggest you use clear pine (without knots) as the most easily breakable material. We also feel that hitting with a closed fist, not the open hand of the karate chop, is less likely to present any problems.

Good luck, lecture-demonstrators. Heeiaa!

Reference

1. Michael Feld, Ronald McNair, and Stephen Wilk. "The Physics of Karate," Sci. Am. 240, 150-158 (April 1979).

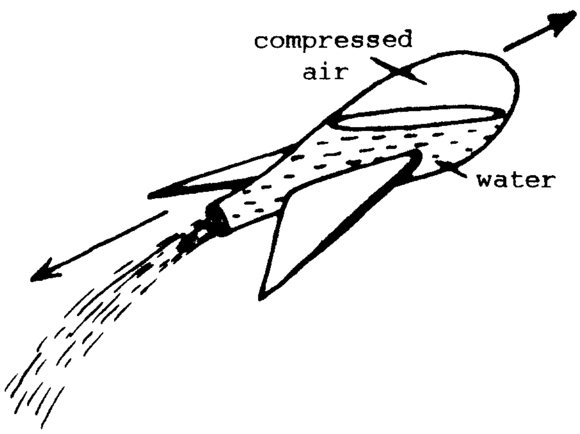
XIX. ROCKETS

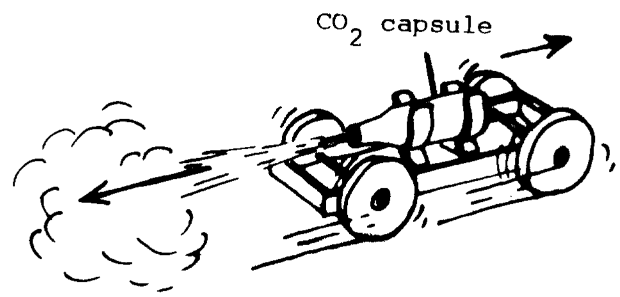
Nuffield O-level Year 4

Apparatus Either 1 water rocket
or 1 CO_2 capsule rocket
Spare CO_2 capsules

Various water rockets are obtainable from toy shops. (A suitable one is made by Merit: Lunar Rocket, cat. no. 9220). CO_2 capsule rockets are obtainable from toyshops. One manufacturer makes a simple truck to take a CO_2 capsule.

A simpler arrangement: Attach a CO_2 capsule (as used for soda siphons) to the top of a toy truck. The capsule should be horizontal with its neck facing the rear of the truck. Use Sellotape for fixing, or attach an aluminium tube and then fix the capsule inside it.





Procedure

a) Fire a water rocket or b) break the capsule of a CO_2 rocket with a round nail given a sharp blow from a hammer. The truck will move at high speed across the table or floor.

XX. SPECTACULAR ROCKET EXPERIMENT

Evan Jones & P. Peter Urone

In the book, Daybreak,(1) Joan Baez describes what her famous physicist father called the "demonstration of the century." During a lecture at a summer course at Harvard University, Dr. Baez sat astride a carbon dioxide fire extinguisher mounted on a little red wagon and proceeded to propel himself around the room. Our students react to the demonstration as did those of Dr. Baez: with awe followed by applause and shouts of approval.

This memorable demonstration can be developed into an exciting laboratory experience to dramatically illustrate a wide spectrum of principles. It can be used to exemplify Newton's second and third laws, impulse, variable mass systems, the kinetic theory of gases, and many other concepts. For example, the impulse and momentum considerations, applied to a variable mass system, can be used to obtain the exhaust gas velocity and the average rocket thrust(2). If v is the gas velocity relative to the rocket, m is initial rocket mass, Δm is the mass of released gas, ΔV is the increase in rocket velocity, F is the backward friction force of floor against rocket, and Δt is the time of run, then:

$$v = -\left[\frac{m(\Delta v) + F(\Delta t)}{\Delta m}\right]$$

and thrust $\cong -\left[\frac{v(\Delta m)}{\Delta t}\right]$

Calculation of the kinetic energy imparted to the rocket and to the gas reveals the fact that the gas receives by far the most energy, despite both gas and rocket having received an impulse of the same magnitude.

The obvious cooling of the exit gas can lead to a discussion of adiabatic processes, and even to the mechanisms by which clouds are formed in the atmosphere. The kinetic theory of gases can be introduced to determine the root-mean-square molecular speed of the exit gas.(3) The acoustic speed may be calculated for comparison with the experimentally-obtained exit gas velocity.(4) The exit velocity (210 ms^{-1}) compares well with the calculated acoustic velocity of CO_2 (217 ms^{-1}) at 195K (sublimation temperature at atmospheric pressure).

To perform the experiment we first remove the exhaust horn from a ten-pound-charge fire extinguisher, rest the cylinder in the wagon, and bolt the exit nozzle firmly (!) to the wagon. As the driver opens the valve, the rocket accelerates through a measured distance (usually 10 m).

Final rocket velocity may be measured with a photocell gate or with a stopwatch. Mass of released gas is determined by weighing the gas cylinder before and after the run. Frictional force is obtained by pulling the loaded rocket with a spring scale, at constant velocity.

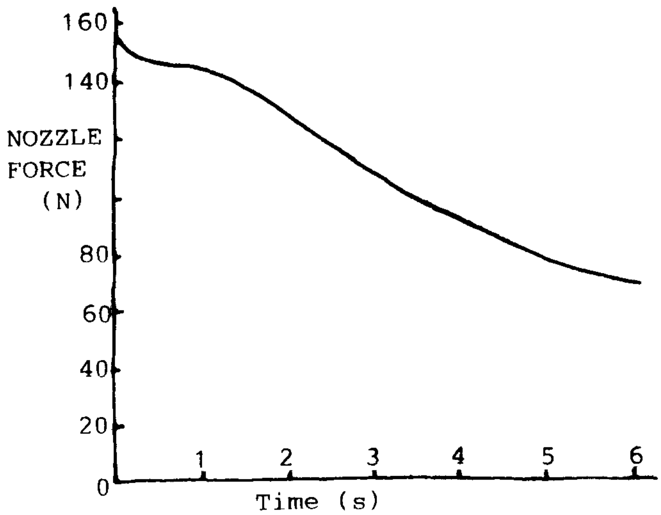
For comparison, the rocket thrust on the gas can be measured directly with a force transducer. The rocket nozzle is clamped to an aluminum arm to which a pair of tension springs is attached. One end of the arm pivots on a hinge, and the other end activates a linear potentiometer (e.g., Pacific Scientific Co., RP04-0101- 1) as the force at the nozzle changes the equilibrium position of the arm. The linear potentiometer is wired as a voltage divider, and operates a recording potentiometer. This transducer is easy to build, safe to operate, and has fast, accurate response.

Figure 4.23 shows the force-time relationship obtained with the transducer. The area under this curve can be compared to the total impulse on the gas, as calculated for the 10 m run.

Typical data and results are shown below:

Distance:	10 m
Time:	3.5 s
Final rocket velocity:	3.8 ms^{-1}
Initial rocket/driver mass:	81 kg
Gas released:	1.9 kg
Rolling friction:	22 N
Average exit velocity:	210 ms^{-1}
Total impulse on gas (experimental):	390 Ns
Total impulse on gas :	450 Ns
Average Rocket power:	127 W
Average Gas power:	9700 W

Any gas under high pressure demands careful handling. The valve and hose should be protected from damage, and the hose should be secured to the wagon at several points. Wagon speed should never exceed 4 ms^{-1}. Blast off!



References

(1) J. Baez, **Daybreak** (Avon, New York, 1966), p.63.
(2) R. Resnick and D. Halliday, **Physics Part I** (Wiley, New York, 1962), pp.198-203.
(3) Ibid, pp.577-578.
(4) Ibid, p.587.

XXI. ROCKET SLED DEMONSTRATION

Tim C. Ingoldsby

A simple, low-cost, and highly stimulating demonstration of the impulse-momentum theorem can be made by converting an ordinary dynamics cart into a rocket sled. This is accomplished by fastening a simple solid fuel model rocket, to the dynamics cart with masking tape.

The total impulse of the engine is given as one of the specifications. By determining the mass of the cart-rocket- engine system, one can predict its final velocity using the relation $F\Delta t = \Delta(mv)$. The small mass change caused by the propellant burn (typically, less than 0.5%) can be overlooked. By attaching a piece of cardboard to the cart a photocell gate can be triggered, and the final velocity can be compared with that predicted by the above equation.

This demonstration can be done inside, even on a wooden floor, if the following suggestions are followed:

(1) Use a booster-type engine (such as the Estes A8-0, B6-0, B14-0, or C6-0), as such engines do not contain a colored smoke-delay charge.
(2) Remove, or protect with recovery wadding, the parachute to avoid melting the plastic as the engine burns out.
(3) Put down some sort of covering, such as butcher paper, on top of the floor to protect against smoke discoloration to the floor.
(4) If an engine with a short thrust duration is used, the photocell gate can be set up within about 2 m of the cart's initial position, as the thrust will be completed before the cart has moved more than about 1 m.

Results achieved with this demonstration have been remarkably accurate and the excitement generated in the students can easily lead to further experiments with rockets.

XXII. DEMONSTRATIONS WITH ROCKETS

Project Physics

Introduction

The demonstration experiments suggested here can accomplish two things. They are exciting, which makes them ideal as motivating experiments at the beginning of the course. Rockets and space flight are matters of great public interest today, and experiments like these could do much to arouse interest (and perhaps increase enrollment) in a physics course. The experiments can also be used to teach quite a lot of physics: free fall, force, impulse, conservation of energy, application of trigonometry, etc.

We cannot stress too strongly the need for strict supervision by the teacher at all times. Get permission and support from local officials and school administrators before starting model rocketry.

Small solid-fuel rocket engines, lightweight rockets, and a considerable body of supplementary information can be purchased from Estes Industries, Inc., Box 227, Penrose, Colorado 81240. Their catalog is available on request from the address given. We have tested the "Scout", the "Corporal", and the "V-2". Assembly for these models ranges from 1 to 2 hours and could be done by students.

When used with some care under strict supervision of the teacher, these rockets are probably considerably safer than a good number of other experiments that are performed in the classroom. However, students should not be permitted to take home rockets from the school's supply or to use the school's rockets during school hours without careful supervision. Although quantitative experiments of real precision are probably mathematically too involved, students can learn much from a series of demonstrations that permit some student participation.

Rocket engines come in a variety of sizes with maximum thrusts of either 6 N or 39 N and thrust durations from 1.7 s to 2.0 s. In addition, a special-purpose engine (B.8-O(P)) for use in static tests is available.

Experiments with rockets in free flight

If a large, open space is accessible to the class, a number of experiments can be performed with free-flight rockets. For example, one may use successively more powerful engines in several otherwise identical rockets. Another set of experiments would make use of rockets of identical exterior design but of different mass; in fact, one might make one of the rockets so heavy that it will not lift off. We all get a thrill from firing the small rocket and seeing it rise rapidly. Students should stand at known distances, at least 30 m from the launching pad, each with a simple altimeter, consisting of a protractor with a small plumbline and a viewing tube, made, for example, from a large soda straw (Figure 4.24).

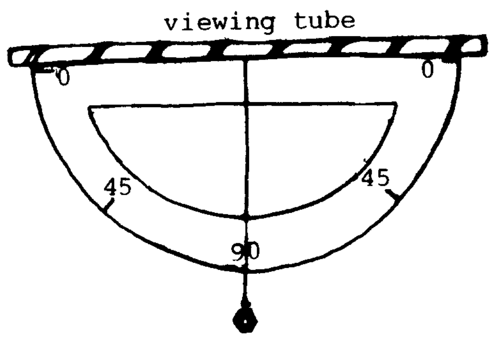


Fig. 4.24.

Each student should try to measure the angle of elevation of the rocket at the same moment, preferably when the rocket has reached its maximum height. The teacher can call out the time for this measurement. Using simple trigonometry, students can calculate the height of the rocket. If there is little wind and the rocket rises vertically, they can calculate the height knowing the distance and elevation angle.

(....................)

This part of the project is completely open-ended. Students can undertake a systematic experimental study of damping forces and begin to appreciate the problems of the scientist or the engineer. They will also begin to realize that through systematic study of a problem one will slowly be able to approach better and better solutions.

This demonstration can teach a good deal about free fall, propelled flight, the operational meaning of force, momentum, conservation of energy, the use of trigonometry, experimental uncertainty, and the scattering of data; but it can also be justified as a motivating experiment that is interesting and exciting. Rockets and space flight today hold a unique position in the public eye. It seems reasonable to make use of this interest in attempting to attract students to the physics course. There is no question that the news of such firings in a course will spread rapidly through a school. As a consequence, students who otherwise might not have found out about the excitement and challenges of physics may become interested.

XXIII. MODEL ROCKETS AND MICROCHIPS

Charles P. Fitzsimmons

WHEN IT'S TIME FOR MODEL ROCKETS, DON'T JUST BUILD AND LAUNCH THEM. ANALYZE THEM!

NASA wouldn't think of launching a rocket without computers monitoring thrust, trajectory, altitude, and every other factor crucial to the success of the flight. If you have access to a microcomputer, now your class can make use of similar, though smaller-scale, technology in their own rocketry studies. So get out the model rocket parts and plug in the Apple (or Commodore, or other computer).

Model rocketry helps you to teach about the principles of space flight the way nothing short of a Space Shuttle mission can. Students can understand the tracking of flights, the concept of the payload, the force needed for launch, and myriad other concepts when they have a chance to work with model rockets. But sometimes students can bog down in the calculations and never surface to an understanding of the principles. Here is where the microcomputer can help.

Once students understand the principles behind the calculations and how every factor fits into the spaceflight equation, the computer can gather data, do the number-crunching, and print out the results with a precision your students could never come close to. The microcomputer is a science tool the way the model rocket is - and with this exercise, students can learn to make the most of both.

By the time my eighth graders launch into their model rocket project, they have completed a 12-week unit on astronomy and space travel. I divide them into groups and give each group a packet of information and 2 weeks to accomplish its objectives. The packet explains the purpose of the project - to design, construct, test, launch, and recover a model rocket.

You can have students build model rockets from kits or you can let them design and build their rockets from parts. I prefer to let students work from parts, which I supply along with a price list. I evaluate their completed rockets on the basis of design, quality of construction, and cost (just as the government does with the space program; students, too, must learn to work economically).

I suggest that the groups divide the chores so that one person designs the rocket, one builds it, one handles safety and testing, and one writes the final report. But the tasks need not be so strictly segregated - everyone should learn about every task.

Every model rocket the students build must meet certain specifications. The rocket must

- be made from standard parts, available as collections of assorted parts with enough to build five or six rockets.
- stand at least 30 cm but not more than 60 cm tall.
- carry a payload of a penny. The payload must be carried inside the rocket and must be returned to me unchanged after the flight.
- be capable of more than one flight and be recovered safely.
- reach an altitude of at least 150 meters.

Be sure also to provide students with safety rules and regulations and to use only standard model rocket engines for the propulsion system.

The microcomputer comes in when it's time to analyze the rocket's flight characteristics, to certify that the ship is stable and safe to fly, and to accurately estimate the altitude the model will reach.

Before they actually build the rocket, I have my students complete the following requirements:

- Draw to scale the model rocket and at least two alternate designs.
- Prepare a list of parts used.
- Write a report on the construction details, including a description of how the payload requirement is to be met.
- Summarize the microcomputer data, including information on the rocket's stability and estimated altitude.
- Select an engine based on the microcomputer data.
- Submit a summary report.

Our microcomputer is used in two different ways. We use it to solve the equations of motion for the rocket's flight and to interface to a test stand to evaluate thrust. Figure 4.25 shows some of the variety of software available to calculate the center of pressure of a model rocket, to estimate the maximum altitude the rocket will reach, to determine the stability of the rocket's design, and to test the thrust of the engine.

You can do all these analyses before the model is built. The programs demonstrate the power of the microcomputer to make repetitive calculations quickly. Eighth graders would not be able to work with the mathematics of these calculations, and they clearly see the need for the microcomputer.

To use these programs, you must know the thrust, or total impulse, of the rocket's engine. You could look that up in catalogs, but I suggest that students use the microcomputer to determine the thrust themselves. You can use an easily constructed test stand for that purpose (1). We connect this interface device to one of the game paddles of our Apple II+. Then we can construct a graph of thrust versus time and so calculate total impulse.

Table 4.25 Model rocket microcomputer software for the Apple II

Title	Description	Source
Atmos Atmosphere Data	Determines the properties of the standard atmosphere, including temperature, pressure & density.	David Eagle 3759 76th St. SW Byron Center, MI 49315
Rocket 1	Determines the flight performance of a model rocket by calculating maximum altitude, coast time, total flight time, burnout time, velocity at burnout, and engine thrust.	David Eagle
F.R.O.G.S. Fun Rocketry or Great Science	Calculates the time of flight, altitude, velocity, and acceleration for the entire flight of a model rocket. Written as a tutorial. Helps students to understand the mathematics of model rocket flight.	Terry Flower Physics Dept. College of St. Catherine St. Paul, MN 55105
Time-Thrust Engine Testing Program	Used with an interface, which is connected to the game port of an Apple II computer, to draw time-thrust curves of model rocket engines.	Chuck Hosler Dept. of Chemistry Univ. of Wisconsin Lacrosse, WI 54601
Rocketry Center of Pressure	Calculates the center of pressure for simple and complex model rockets. From an article in Creative Computing, May 1980. The article contains a complete discussion of computer aided model rocket design.	Keith Schlarb 5617 Indianolia Ave. Worthington, OH 43085

CP-CG-80A Model Rocket CP-CG	Calculates the center of pressure of a model rocket if the center of gravity is known and determines whether the model is stable.	G. Harry Stine Estes Industries Penrose, CO 81240
CP-CG-80B Model Rocket CP-CG Calculations	Calculates the center of pressure of a model rocket.	G. Harry Stine
MRDR-80E Two-station Alt-azimuth Altitude Data Reduction	Determines the height a model rocket will reach. Uses the data from two stations that supply azimuth and angular altitude and then does the mathematical calculations to determine the height of the rocket.	G. Harry Stine
RASP-80E Rocket Altitude Simulation Program	Accurately predicts the altitude of a model rocket using the MKS system of units. Program RASP-80EE uses the English system of units.	G. Harry Stine
Stabcalc-1 Rocket Stability	A complete model rocket stability calculation program for simple and complex rockets. Calculations. pa.	G. Harry Stine

Our model rocket project does involve some expense. It requires a variety of model rocket parts and engines. I provide enough parts for students to choose among, which costs about $30 for a class of 30 students. Consider buying several altitude finders, too; the groups can share them.

If the expense is a problem, you could have students make homemade rockets out of sheets of paper and cardboard. That way, students also get practice measuring and drawing. But this approach adds to the time required for the project.

Model rocketry is a great pursuit for beginning earth science students. But it's also great for teachers. Try building a model rocket yourself first, to give yourself the confidence to try the project with your students. If you follow the National Association of Rocketry safety code (2) and your own common sense, these activities are perfectly safe for your students. The microcomputer also helps us ensure the safety of the rockets.

This kind of group exercise builds student interest and cooperation. The whole class can judge the success or failure of these group projects out on the launch pad, so group members work earnestly together to meet the challenge. Some of these students have never before successfully completed a group project - a safe launch and recovery means a great deal to the groups. And the microcomputer testing helps groups work out the bugs before they get to the launch pad. That means a better chance for success, and a better feeling about science. So why not take off with model rockets and microcomputers in earth science this year?

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1. Hosler, C. "Engine Measurement With Home Computers." **Journal of the National Association of Rocketry** 25:6-7, October 1982.
2. For a copy of the code, write to the National Association of Rocketry, 182 Madison Dr., Elizabeth, PA 15037.

XXIV. HOW TO PHOTOGRAPH A ROCKET

Russell Edwards

A water rocket made from a detergent bottle is a useful way of demonstrating rocket propulsion.

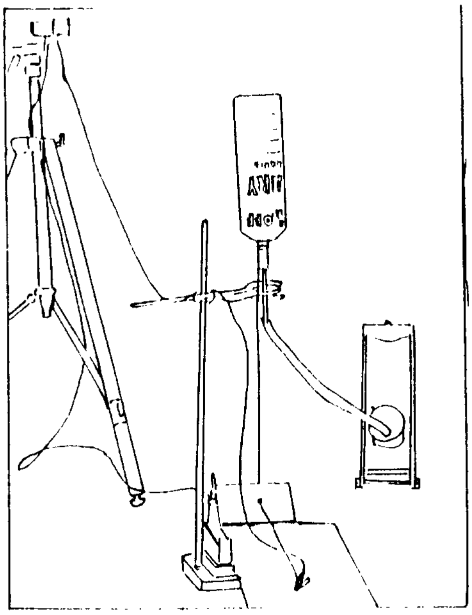


Fig. 4.26 The rocket on the launch pad ready for firing. The copper plate and cotton firing mechanism is in the foreground.

A plastic detergent bottle is half filled with water and attached to a car foot-pump with a piece of rubber tubing, the other end being made to fit tightly into the mouth of the bottle. When air is pumped into the inverted bottle, loosely held in a retort stand, the pressure builds up until it is great enough to thrust the water out, propelling the bottle high into the air.

Unfortunately the rocket lifts off so fast that it is impossible to see the water being thrust out of the bottle or to photograph it in the normal way.

The following method was used to obtain a picture of the rocket. After setting up the rocket on its gantry, a piece of cotton was tied round the neck of the bottle and passed through a hole in a metal plate immediately below the rocket. Attached to this cotton was a metal lead which goes to one terminal of a flashgun (it will be necessary to remove the flashgun plug, which normally fits into the camera). The other flashgun terminal is attached to the metal plate by a length of wire. As the rocket lifts off, it pulls the cotton thread through the hole until the metal wire touches the plate, thus completing the circuit and firing the flashgun.

To take a picture, the camera is set on a tripod focused on a position immediately above the rocket where it will be when the flash goes off. The camera shutter should be opened and kept open on the B or T setting so that synchronization with the flashgun is unnecessary.

All equipment should be wrapped in plastic bags to keep the apparatus dry as the water from the rocket is thrown over a wide area.

XXV. TRAFFIC ACCIDENT INVESTIGATION

P.K. Tao

Traffic accident investigation is not just examining the damage to vehicles and injuries to persons and taking statements from witnesses at the accident scene. It also involves applying the principles of mechanics to determine how the accident happened.

The mechanics principles involved include, among others,

* Friction
* Uniform acceleration
* Newton's laws of motion
* Conservation of linear momentum

The investigation consists of 2 parts:

* **At-scene investigation:** Examine damage to vehicles and injuries to persons, study tyre marks left on the road, take statements from witnesses, make measurements on the road for preparing a scale plan of the accident scene, etc.

* **Accident reconstruction:** Consider all evidence, apply the principles of mechanics, conduct skid test, prepare reconstruction on a scale plan, form hypotheses and carry out tests, etc.

Based on the findings, the investigator **makes inferences** or **forms opinions** on how the accident happened.

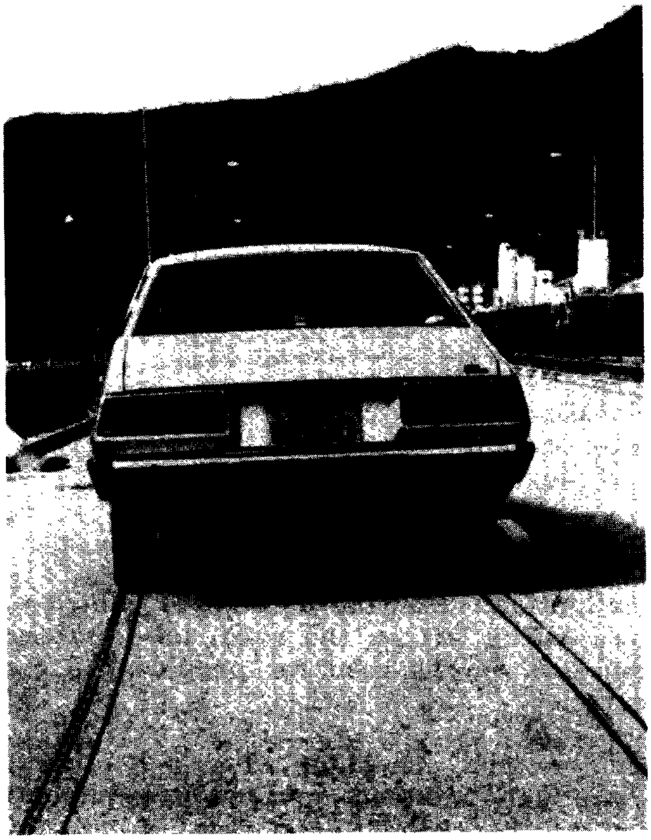
Accident reconstruction (AR) is especially useful when the events of an accident are not fully known, are conflicting or in dispute. The findings are generally accepted as expert evidence by the court.

AR was pioneered by the Traffic Institute of Northwestern University, U.S.A., in the 1940s. It is now widely practised as a standard method of traffic accident investigation in many countries.

SPEED ESTIMATE FROM SKID MARKS

When a driver sees a hazard and applies emergency braking, the wheels are locked and the car skids on the road. The car is slowed down or brought to a halt by the friction between the tyres and the road surface.

As the car skids, tremendous heat develops at the tyres, causing the tarmac on the road surface to melt and, as a result, skid marks are produced.



Skid marks are important clues to traffic accident investigation. From their lengths, the speed of the car prior to skidding can be estimated using simple principles of mechanics.

(..................................)

SKIDDING TO A KNOWN SPEED

In cases where a car collides with another car or a fixed object before skidding to a halt, the speed at the start of skidding can be estimated if the impact speed v is additionally known.

The decelerating force is the tyre/road friction

$$F = -\mu mg = ma \text{ (Newton's 2nd Law)}$$

Hence $\quad a = -\mu g$

Applying the equation for uniform acceleration $v^2 = v^2 + 2as$, and substituting $a = -\ \ g$, we have

$$u = \sqrt{v^2 + 2\mu gs}$$

The impact speed can be estimated from the damage to the vehicle or by applying the principle of conservation of momentum.

EXERCISE 2

A car skids with all four wheels locked for 38.5 m and then runs into a tree. The impact speed of the car is estimated from the damage to be about 40 km/h. The coefficient of tyre/road friction is found to be 0.76. Estimate the speed of the car prior to skidding.

(..............................)

COEFFICIENT OF TYRE/ROAD FRICTION

For a passenger car or a light van on a dry, unlubricated road, the coefficient of friction depends only on the nature of the tyre and the road surface and is independent of the weight of the car and the tyre conditions (pressure, tread pattern, depth and area, etc.). Its value differs slightly with speed, being lower at high speed, but may be regarded as constant for speeds between 40 and 120 km/h.

Typical μ values of various road surfaces (tarmac, concrete, gravel, etc.) under different conditions range from about 0.4 for trafficpolished road surfaces to almost 1 for dry, hard and gritty surfaces. On a wet or icy road, the value may be as low as 0.1.

(..............................)

SKID TEST

A skid test is not always possible at the accident scene - the stretch of a particular type of road surface may be too short or the vehicle may have skidded onto a pavement or a stretch of grass. In such cases, a sled is used. This consists of three or four tyre sections fixed onto a wooden board. The sled is pulled with a horizontal force (measured with a spring balance) to slide steadily on the surface (see photo).

Coefficient of friction = pulling force/weight of the sled.

EXCERCISE

A sled is pulled with a spring balance to slide steadily along a concrete pavement. The spring balance reading of average pulling force is 6.5 kg. The sled is weighed with the same spring balance and the reading is 9.5 kg. Calculate the coefficient of friction between the tyre and the pavement. (-----)

COLLISION ANALYSIS

The principle of conservation of linear momentum can be applied to the collision of vehicles. However, this depends on whether the paths of travel of the vehicles and their velocities before and after impact can be reliably determined.

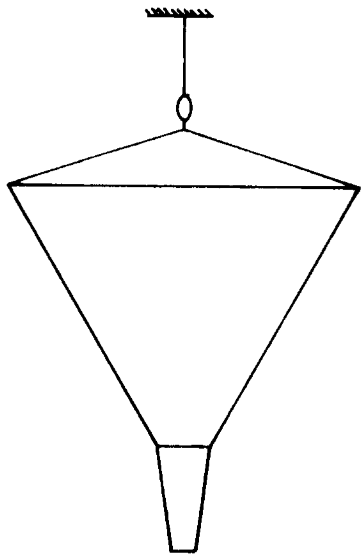
A detailed **scale plan** of the accident scene is required for collision analysis. On the plan should be marked all the observable results of the accident, viz. the final positions of the vehicles, their damage, various tyre marks left on the road, etc. Based on this information, the investigator determines the point of impact, the direction of approach of the vehicles before impact and the direction of separation after impact.

* The **point of impact** can usually be located by scratches and cuts on the road surface and/or an abrupt change of skid marks.

* The **direction of approach** of the vehicles can be determined by the skid marks, traffic conditions at the scene, etc.

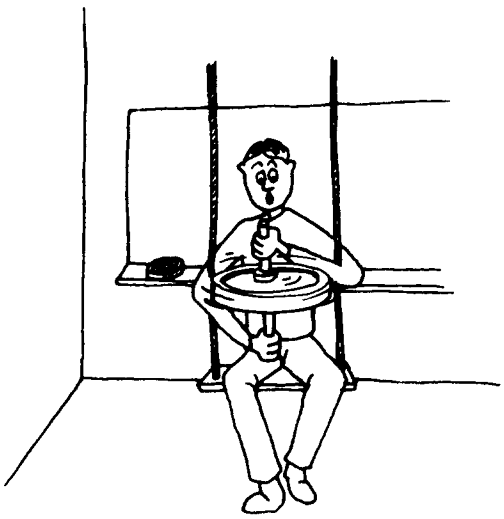
* The **direction of separation** of the vehicles can be determined from the final positions of the vehicles in relation to the point of impact.

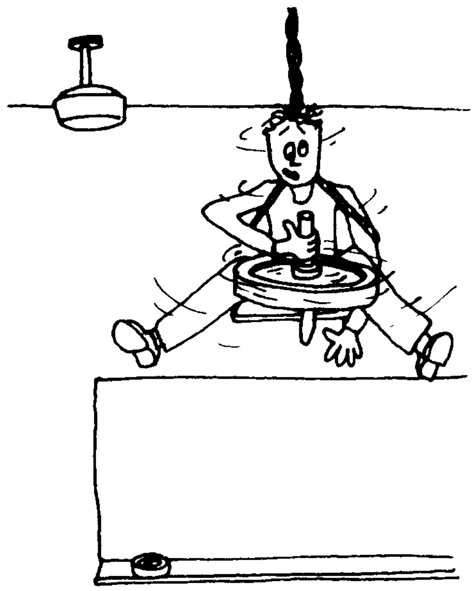
XXVI. DEMONSTRATING CONSERVATION OF ANGULAR MOMENTUM David L. Mott



A simple demonstration of this important law can be made with a funnel and some sand. The funnel we use is made of tin, with a top diameter of about 15 cm. Several heavy copper wires are soldered to the top rim so that the funnel can be freely suspended on its axis. At the suspension point, a low-friction swivel is used, of the kind found in a fishing-tackle store.

The funnel is filled with sand and given a slight initial spin. As the sand comes out the spout, the funnel is seen to spin faster and faster, demonstrating the conservation of angular momentum.





XXVII. ANGULAR MOMENTUM Michael J. Williams

The raising and lowering of a skater's arms is often cited as an illustration of the conservation of angular momentum. I needed a really simple demonstration rather than a complex model and have devised a version using an 18 cm length of plastic hose-pipe and a metre of cotton.

The cotton is threaded through the pipe which is held as shown in Figure 4.27. Twenty turns will wind the thread sufficiently and it is then set to unwind slowly - one turn a second - as shown in Figure 4.28. Just before the thread is fully unwound it will readily slip over itself and by a lowering or raising of one thread the pipe can be made to change to a vertical position. The rate of spin will increase dramatically now its mass is close to the vertical spin axis, Figure 4.29.

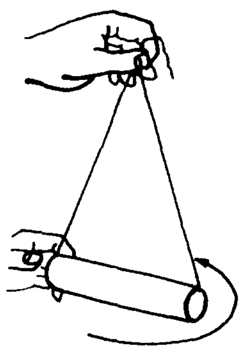


Fig. 4.27

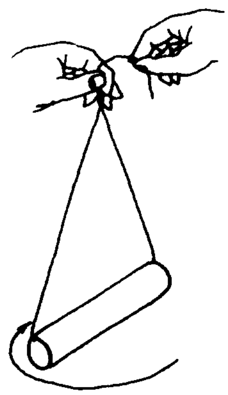


Fig. 4.28

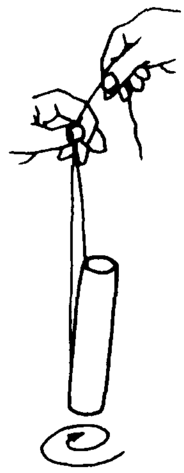


Fig. 4.29

Before the thread has become too twisted again the position and slow rate of turn may be restored. It is this second change that makes the demonstration a convincing one. For the argument that pulling a thread has given more speed may not be used for both changes!

The experiment may be performed with the original pipe position vertical, changing to horizontal and then back to the vertical. It seems wise to keep the centre of mass at the same vertical height throughout these demonstrations to avoid charges of extra potential energy. The demonstration does provoke keen discussion, but the illustration is most clear.

I need this demonstration to deal with a project on space stations with solar mirrors that moved outwards. Other areas are in the expanding earth theory, and the spin of contracting neutron stars.

XXVIII. CONSERVATION OF AN ANGULAR MOMENTUM

D.H. Williams

I find this simple gadget a convincing way of demonstrating the conservation of angular momentum: much more effective than talk about ballet dancers and ice-skaters in Central Africa!

In the diagram, C is a central block of wood, attached to floor parts F, F, 6 mm timber inclined at 20° to the horizontal; with side pieces S, S on both sides of the floor pieces. M, M are standard masses (1 kg, 2 lb) which fit between the side pieces S. They would slide down F to the centre, but are retained at their outer positions by the thin cotton thread T, which is tied to the ring of one mass M, passes over the pin P on one side to another pin P on the other side, and so to the ring of the other mass. The whole arrangement - perhaps 60 cm long - is hung from a long nylon fishing line tied to the hook H.

The thing is given a twist to make it rotate, which it does at closely constant angular velocity. When the students have watched it for long enough to assess its speed visually, a flaming match is held beneath the thread, which snaps, allowing the masses to slide down to C, much decreasing the moment of inertia and so much increasing the angular velocity, plain even to the eye.

My first model used a photodiode arrangement to measure the increase of speed, but the current model uses light timber and comparatively large masses, so that the change of velocity is evident and no measurement is required to demonstrate the principle.

The point of burning the thread is, of course, to avoid giving even the appearance of an added torque to the apparatus.

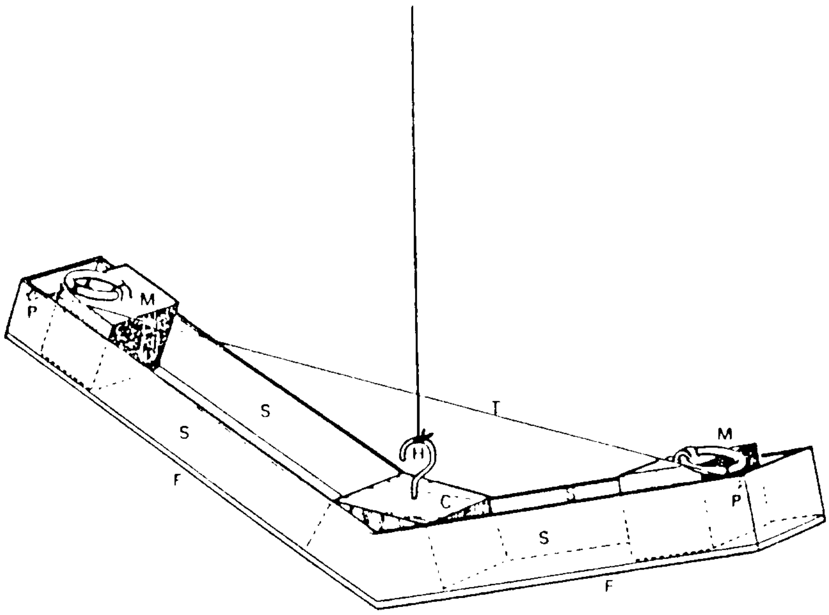


Fig. 4.30.

XXIX. BUILDING A "NO-COST" APPARATUS TO DEMONSTRATE ROTATIONAL INERTIA

Alex Fogel

Rotational inertia is a difficult concept for beginning physics students to understand. Most textbooks illustrate the concept with either a figure skater with arms extended or perhaps a student seated on a free-wheeling stool.

Apparatus to show rotational inertia is available in all of the catalogs, but it is also expensive. What can the budget- conscious physics teacher do? Assemble his own apparatus from parts readily on hand in the lab. One possibility is shown in Figure 4.31.

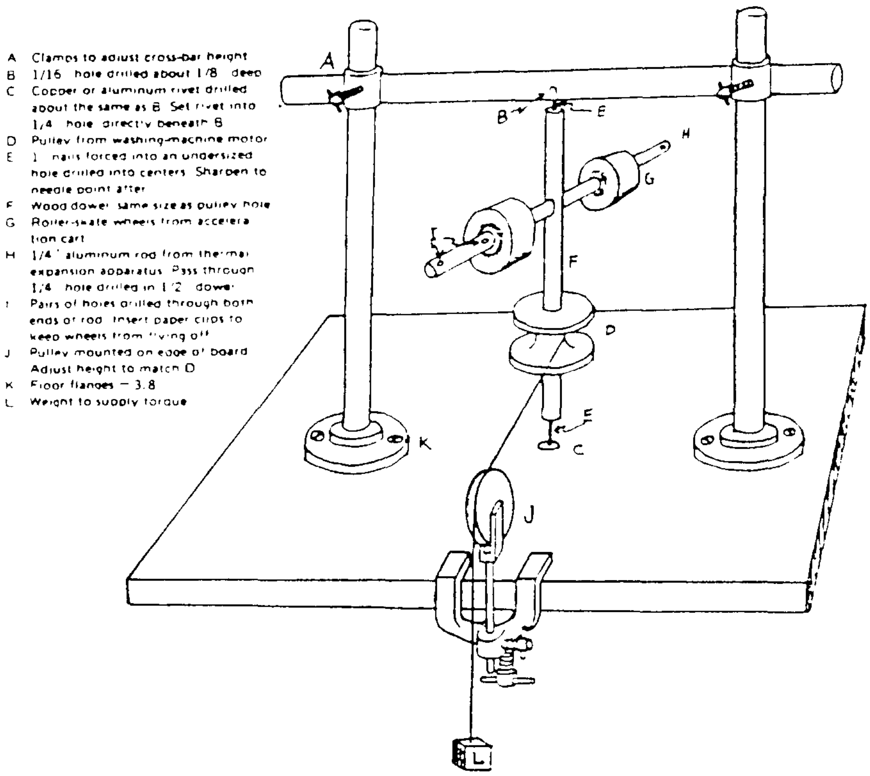


Fig. 4.31.

The angular acceleration is produced by a small weight L (0.5 kg is plenty) falling from pulley J. Dowel F should match the hole diameter of the pulley D, and when dowel F is drilled at each end to receive the 2.5 cm nail, the holes should be exactly on center. Passing the 0.5 cm aluminum rod H through the 1 cm wood dowel requires drilling with some care. The four tiny holes I may be omitted if one chooses to use rubber bands to stop the skate wheels G. The framing is completed by the use of the floor flanges K and clamps holding the bar A. Then the pivot points B and C are located. Since the bar is aluminum and the pivot C is soft copper, there is no difficulty in drilling the holes to receive the nails.

Although no length dimensions are listed, the size of the apparatus was proportioned to the length of the 0.5 cm rod H, which measures 60 cm. This construction results in an apparatus which spins very freely, is easily dismantled for storage and leaves our Physics Department a few more dollars in its budget!

I use this apparatus to show students the relationships of angular acceleration, torque, and rotational inertia. By shifting the wheels on the bar and timing how long it takes for the weight to fall a given distance below the pulley they can easily detect the "resistance" of inertia. The apparatus may also be used to clarify students' concepts of torque and angular acceleration. Measurement of the moment of inertia and comparison with the theoretical value should also be possible, but we have not tried it.

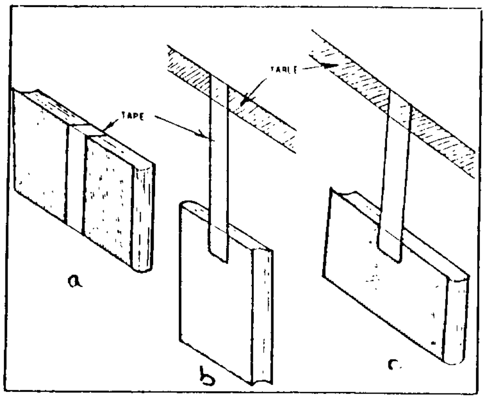


Fig. 4.33.

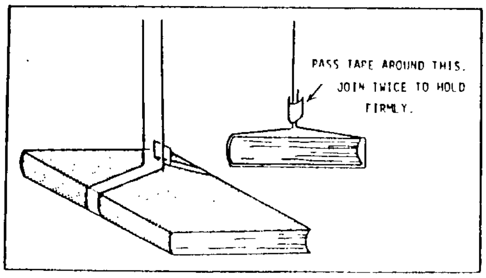


Fig. 4.34

Using 2 cm tape, we can assume approximately that the book is supported by the two edges of the tape as shown in Figure 4.35. The restoring torque as the book is twisted is provided by the fact that as the tape turns, the book is lifted. If the book is rotated by θ , the restoring torque is Fd. F is the horizontal component of the force acting along the edge of the twisted tape. Since the total force acting along each edge is approximately Mg/2, this component is $(Mg/2)\sin\phi$ $Mg\phi/2$. Geometrically we have $\theta d/2=\phi l$.

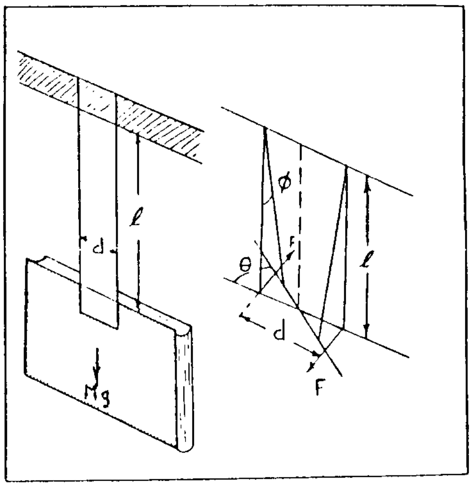


Fig 4.35.

Thus: $F = (Mg/2)\phi = (Mg/2)(d/2l)\theta = Mg\theta d/4l$

The equation for the rotational simple harmonic motion is

$$I d^2\theta/dt^2 = Mg\theta d^2/4l$$

leading to a period $T = 2\pi\sqrt{4lI/Mgd^2}$

Now, $I = M\rho^2$, where ρ is the radius of gyration,

so $T = 2\pi\sqrt{4l\rho^2/gd^2} = 2\pi\rho\sqrt{4l/gd^2}$

By measuring T, you can find and hence calculate I. After you have measured the moment of inertia of the book, you can try an interesting experiment on stability. This works best with a book whose long and short sides differ considerably. With the book taped shut, toss it in the air so that it rotates about the long axis as shown in Figure 4.36a. It will spin quite stably. Now, hold it between two palms and spin it into the air (Figure 4.36b). Again, it will spin stably. Lastly, toss it to spin parallel to the short side of the book (Figure 4.36c). This proves impossible. Instead, the book twists and turns about no one axis. Whereas the first two axes are ones of minimum and maximum moment of inertia, and hence, stable, the third is not. It seems so intuitively obvious that it will spin stably about the third axis that it is very easy to win bets with this trick.

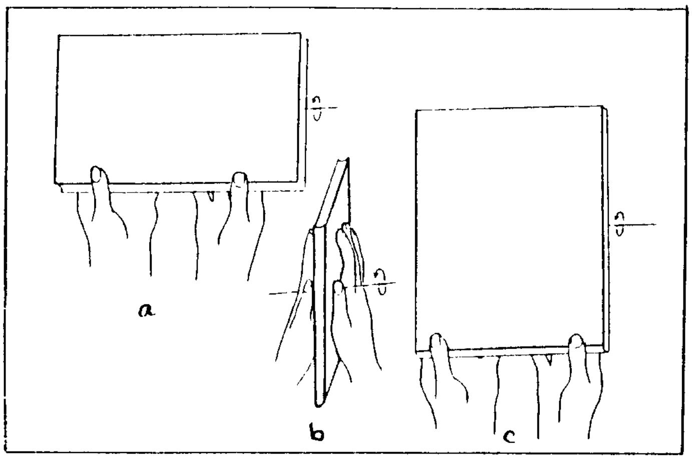


Fig. 4.36.

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I	September 1977	page 339-40
II	Septemebr 1977	page 340-6 (condensed)
III	September 1977	page 356-9

UNIT 2 RESISTING CHANGES

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I	Experiment 68,	page 125
IX	Experiment 67,	page 125
X	Demonstrations 65, 65a, 65b	page 123
XI	Experiment 66,	page 123

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III	8-2.3	page 141
VII	8-1.2	page 136
VIII	8-1.5	page 137
XIII	8-2.4	page 141
XV	8-2.5	page 141-2

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XVI	Vol. 13	1978

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IV	Vol 6	page 477	December	1968	Alfred M. Eich, Jr
VI	Vol 15	page 242	April	1977	Joseph Perez
XII	Vol 12	page 30	January	1974	Paul G. Hewitt
XIV	Vol 1	page 80		1963	
XVII	Vol 5	page 173	April	1967	Herbert H. Gottlieb
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II	Activities, page 35

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V	Vol. 60, No. 211 Dec.1978	page 557

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XXXVI	Vol. 16 page 50, 1981	J. Unsworth, D.A. Unsworth

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V	April	1968	page 179	Charles Rudisill
VI	February	1977	page 108	W. Williamson Jr.,III.,Sr.
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XXXV	February	1975	page 150	Lawrence E. L'Ho
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IL	February	1982 page 102	Lester Evans
L	December	1983 page 618	H. Kent Moore

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III	Pupil's Text - Year 4	Demonstration 38 page 89
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XIX	Teacher Guide - Year 4	Demonstration 16 page 31

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THE INTERNATIONAL COUNCIL OF ASSOCATIONS FOR SCIENCE EDUCATION(ICASE)

Aims

The International Council of Association for Science Education (ICASE) was established in 1973 to extend and improve education in science for all children and youth throughout the world by assisting member associations. It is particularly concerned to provide a means of communication among individual science teachers' associations and to foster co-operation efforts to improve science education.

Activities

ICASE activities include
- publishing a Newsletter and a Handbook for Science Teachers.
- issuing a Directory of Science Teachers' Association Worldwide.
- disseminating information about activities of national and regional groups.
- arranging regional activities in association with other organisations such as UNESCO.
- promoting exchanges of science teaching personnel.
- using its endeavours to promote research in science education.

Membership

Membership is available to:
- National associations for the promotion of science education.
- National associations for the promotion of education through separate disciplines.
- Science education sections of national scientific associations or national educational associations.

Associate Membership is available to:
- Sub-national groups concerned with science education.
- Multi-national associations concerned with regional or international activities in science education.
- Companies and Foundations with interests in science education.

Constitution

The Government Body of ICASE is the General Assembly consisting of one delegate from each member association together with any members of the Executive Committee who are not delegates.

The Executive Committee comprises President, Past-President, Vice-President and up to eight members elected on a geographical basis. The Executive Secretary/Treasurer and Editor are appointed by the Executive Committee. ICASE is closely linked with the Committee on Science Teaching of the International Council of Scientific Unions (ICSU) and thereby enjoys full recognition by UNESCO and other international and national organisations.

Executive Committee