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David Keenahan and Jennifer Keenahan

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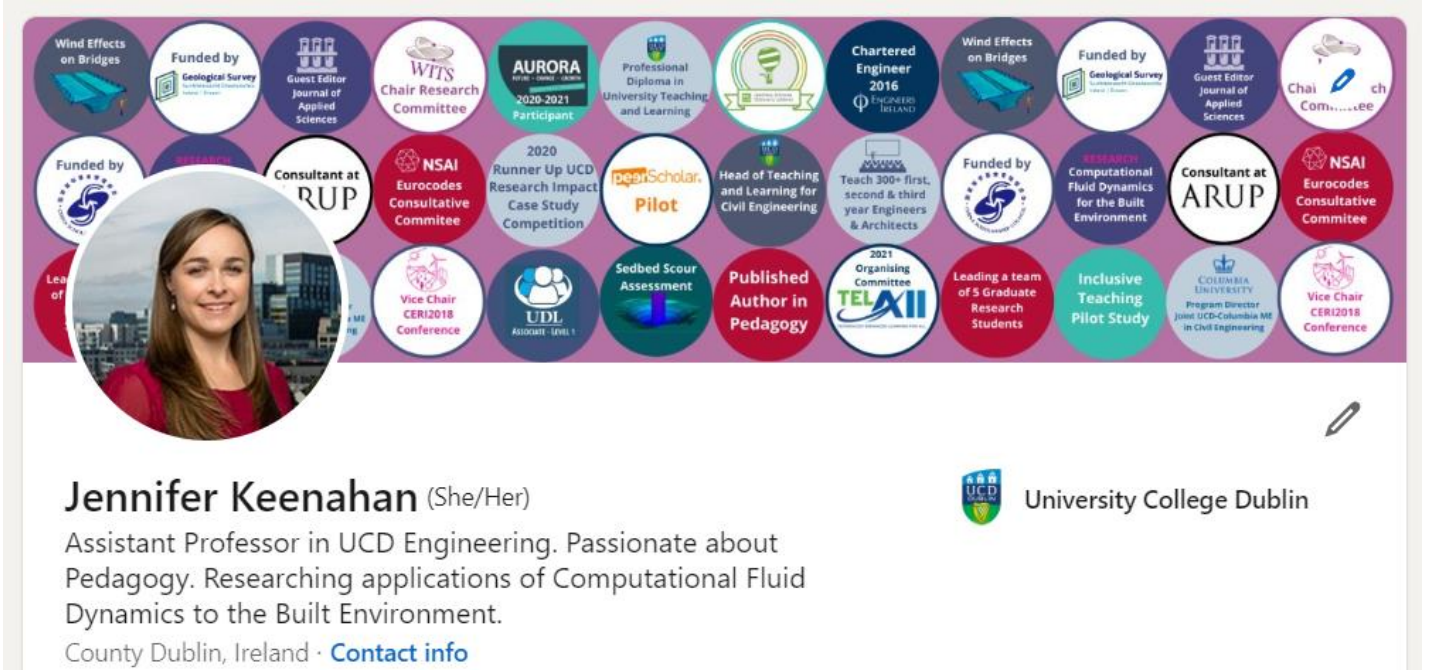


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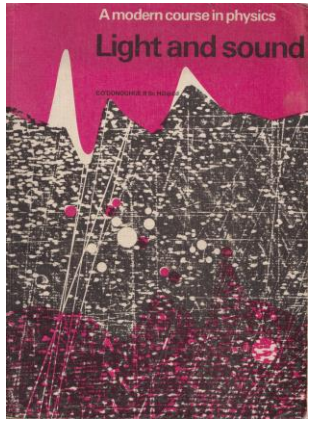
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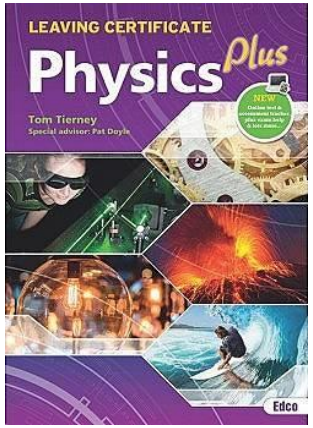
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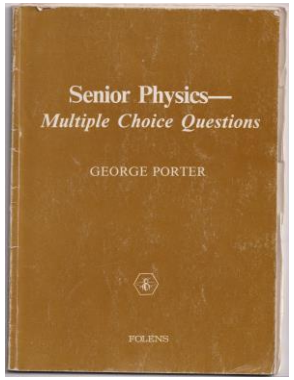
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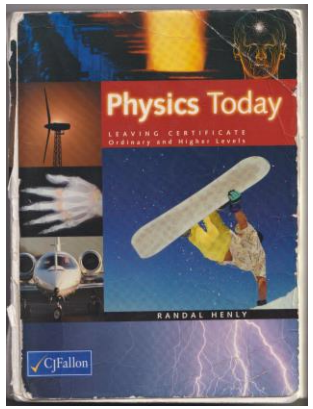
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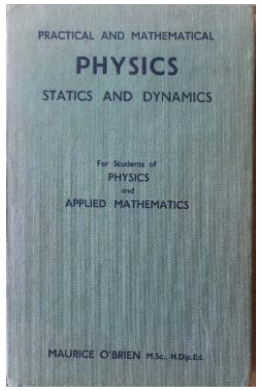
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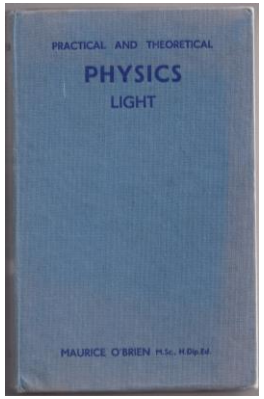
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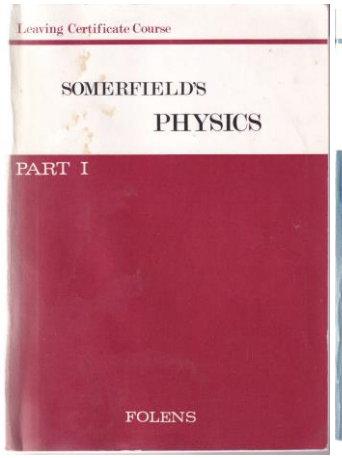
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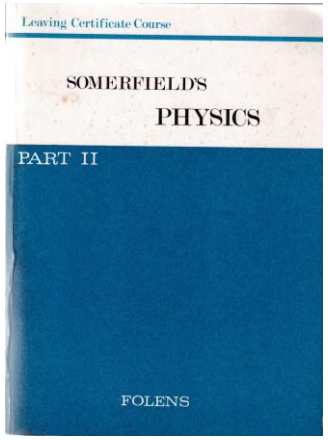
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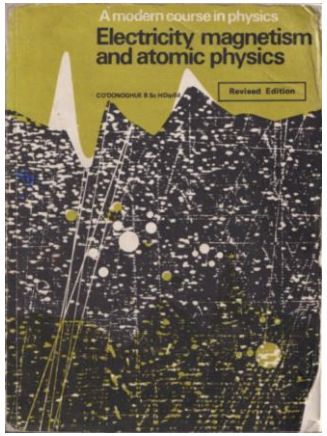
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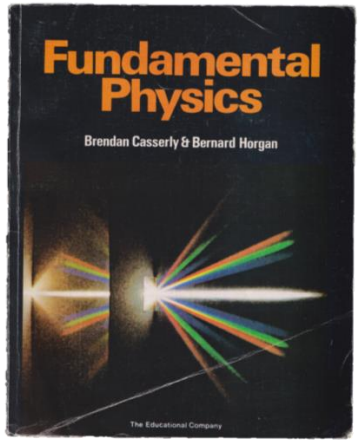
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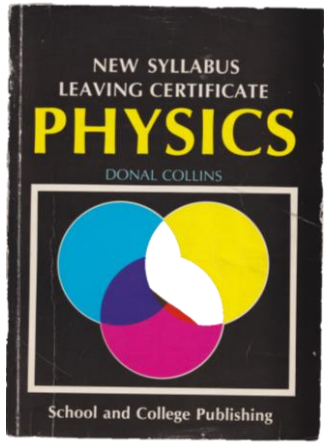
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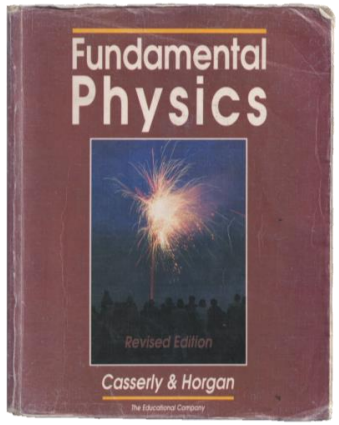
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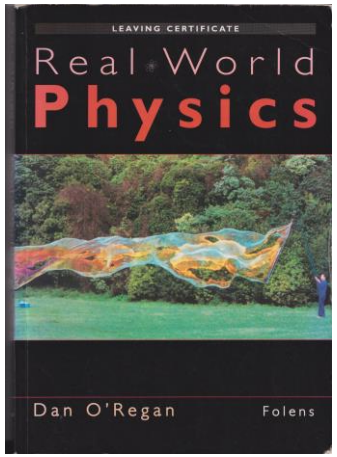
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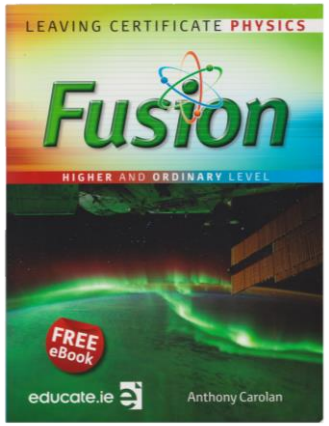
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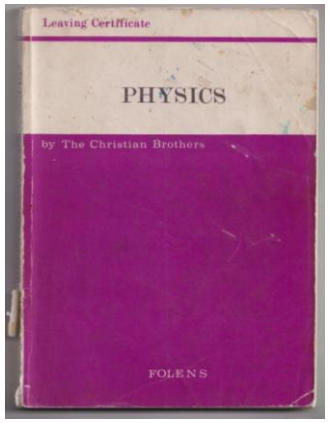
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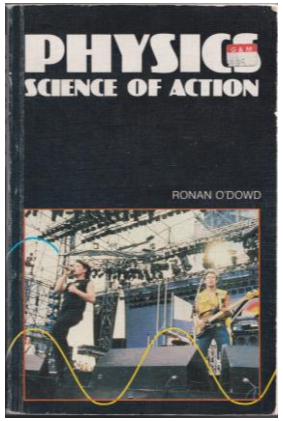
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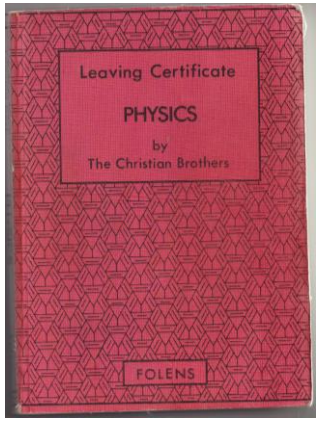
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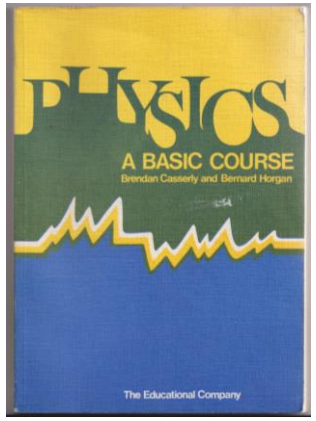
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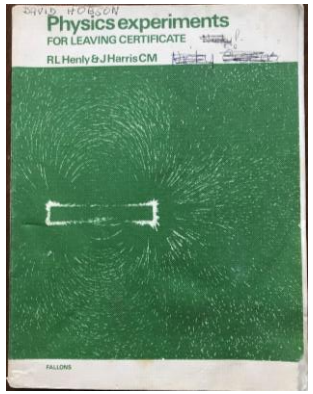
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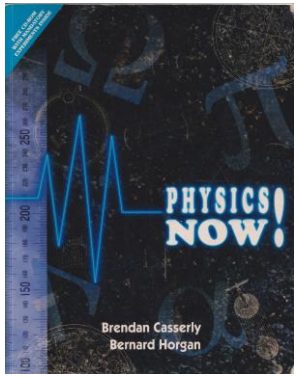
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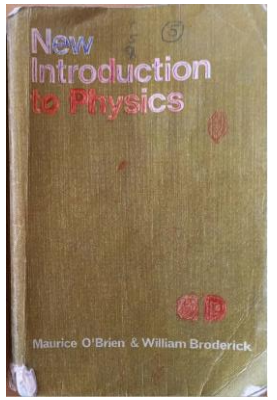
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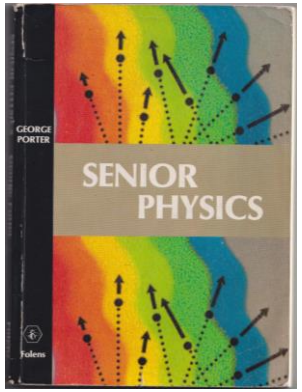
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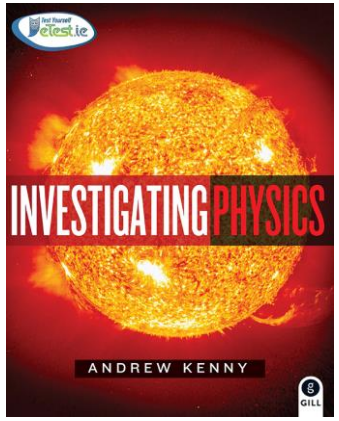
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Did Tyndall influence Physics textbooks?

British physics—the Irish role in the origin, differentiation and organisation of a profession

Norman D McMillan

The development of the modern curriculum subject of physics arose out of several disparate reform movements which led to the modern definition of the term physics, physicist, the first chairs of physics, the first examinations and examiners of physics and the first laboratories for the practical teaching of the subject.

In the 18th century British science became very insular: this coincided with a period of social consolidation after a century of revolution. Consequently many of the important developments in science occurred in nonconformist groups, such as the Lunar Society, and the resultant radical influences played an important part in the development of British physics as it assimilated the French 'physique'. These influences were felt most keenly by engineers at this time, a contributory factor to the early appearance of the engineering profession: the industrial base of British engineering was also well developed by then.

The physics community was then a very middle class group, well represented in the Church of England and established universities, whose members have been referred to as the 'Gentlemen of science'. These enthusiasts for mathematics and the physical sciences were not men committed to professional science in the modern mode, but rather to reforming and shaping science to further their own sectional interests.

The teaching of natural philosophy and physics in all its variegated forms, from the Greek science up until 1850, has been comprehensively studied by Bishop, who pointed out that it was in the dissenting academies in Britain that the Baconian traditions seemed to have survived in their most vibrant form. In Ireland the disadvantaged dissenters made common cause with the Catholics in educational matters. In the early decades of the 19th century educational reform was thus seen as politically expeditious in Ireland, giving that country an important lead over Britain.

The Dublin Society

The colonial societies in Ireland naturally had great political significance to the Protestants, the Dublin Society (later the Royal) in particular. From its establishment in 1731, this body assumed a central cultural role, at the time, unrivalled anywhere in the world. Around the turn of the century it received lavish funds from the Irish Parliament. It had the distinction of being the first centre in the British Isles to offer a scientist the prospect of a 'professional' career.

The Dublin Society became to all intents and purposes, the first polytechnique in the British Isles. It had a truly amazing array of facilities, which included lecture theatres, a library, teaching laboratories, research facilities, the national museum for industry and geology, botanical gardens, agricultural teaching facilities, a veterinary school and, by 1818, an array of some six professors. Several developments were pioneered which led to the establishment of various English Societies including the Society of Arts (later the Royal), the Royal Institution and the London Institution. The Dublin Society had the virtue of being a respectable model for many

Norman McMillan is Head of Physics, Regional Technical College, Carlow, Ireland. A graduate of Portsmouth Polytechnic (B Sc (CNAM)), he obtained his Ph D from the University of Nottingham before doing postdoctorate work at Trinity College Dublin. As well as his interest in the history of physics, on which he has written both books and articles, he has interests in optoelectronics (with inventions to his name), materials science and technical/physics education, in which fields he has also published. He constructed the 1985 Travelling Science and Engineering Exhibition, seen by over 100 000 youngsters, and organised and founded both the Tyndall Schools Lectures and the Science and Engineering Exhibition Centre of Ireland.

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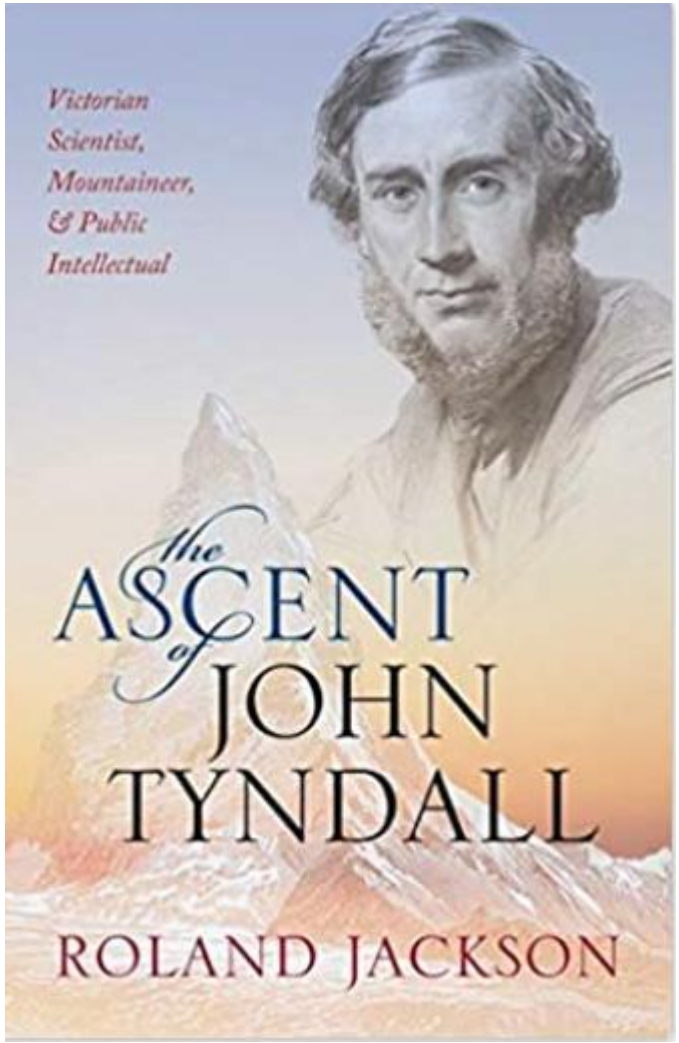
Tyndall

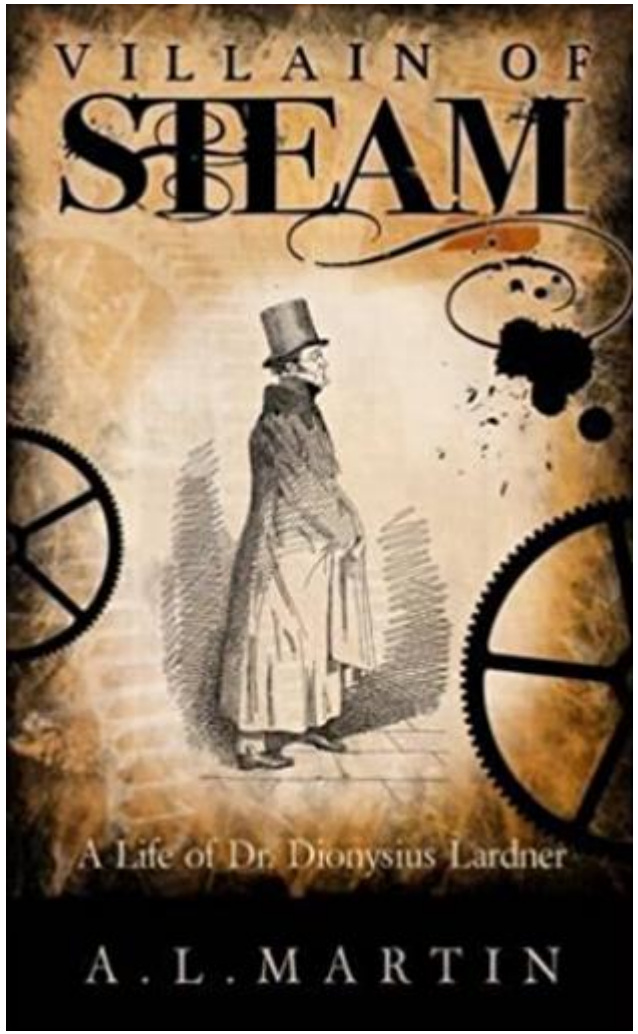
Lardner

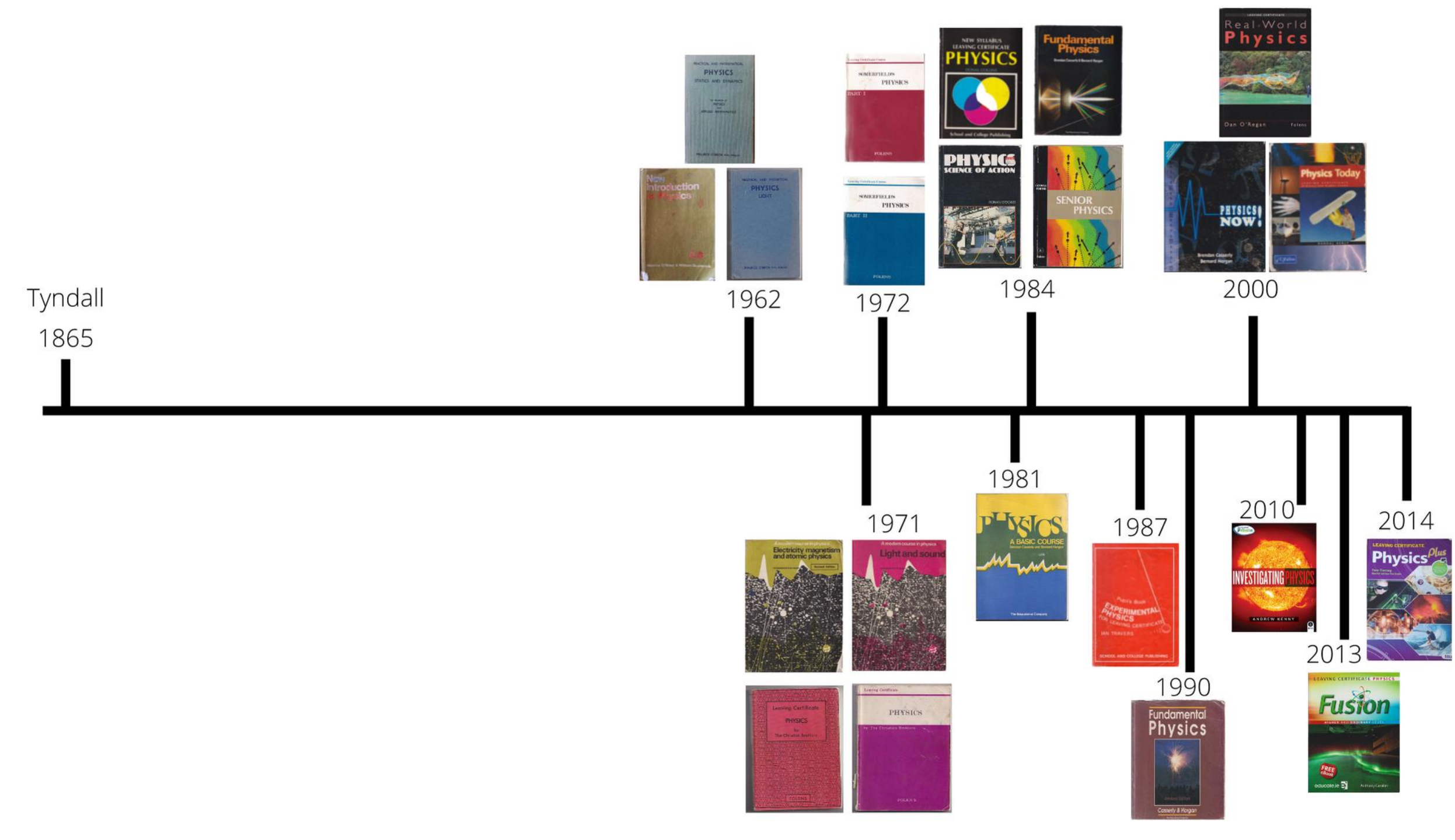


Two recent biographies:

Tyndall
by
Roland Jackson

Lardner
By
Anna Martin




Tyndall
1865
1962
1972
1984
2000
1971
1981
1987
1990
2010
2013
2014
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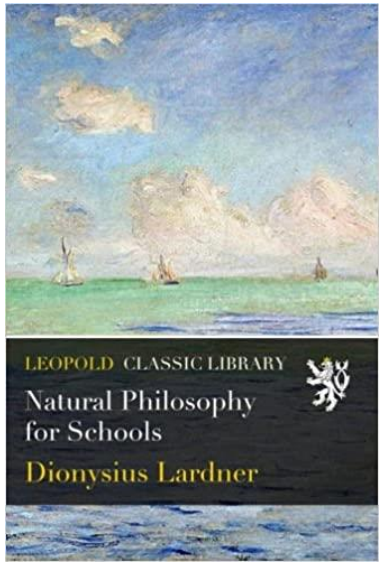
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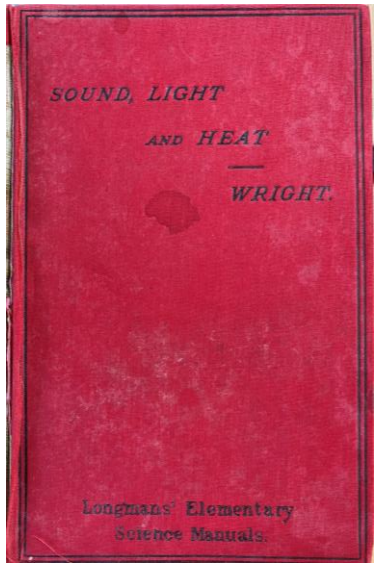
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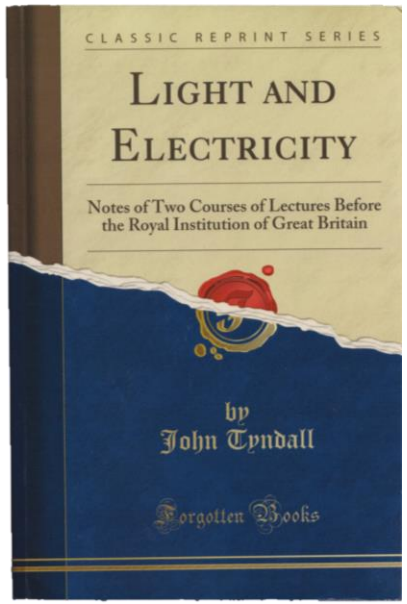
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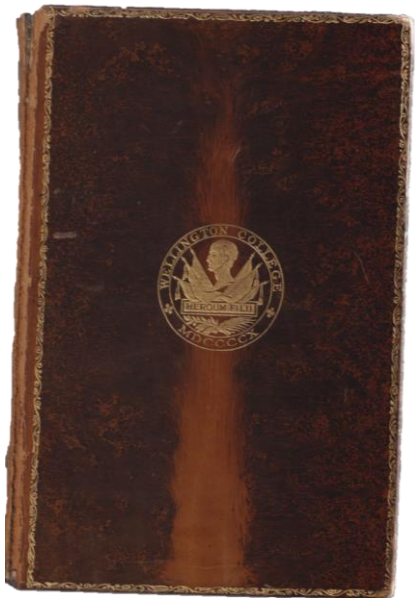

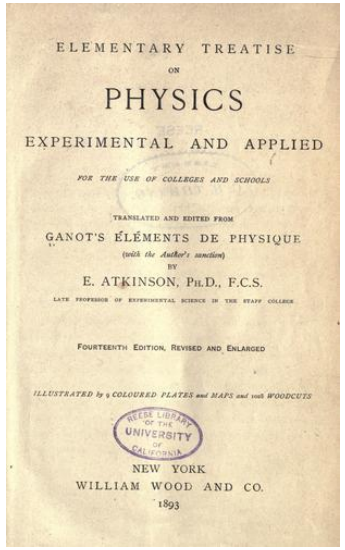
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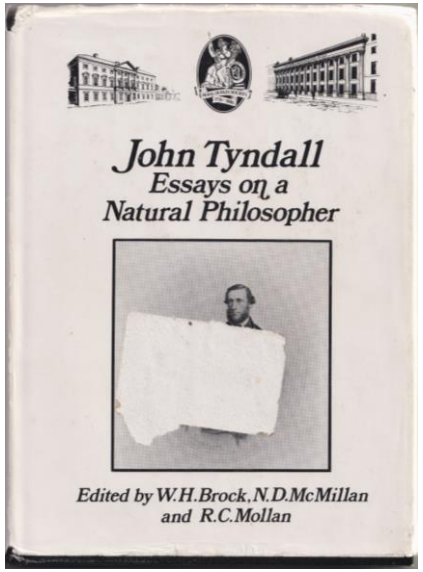
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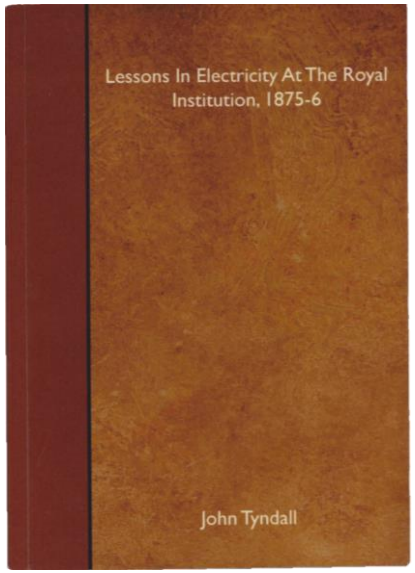
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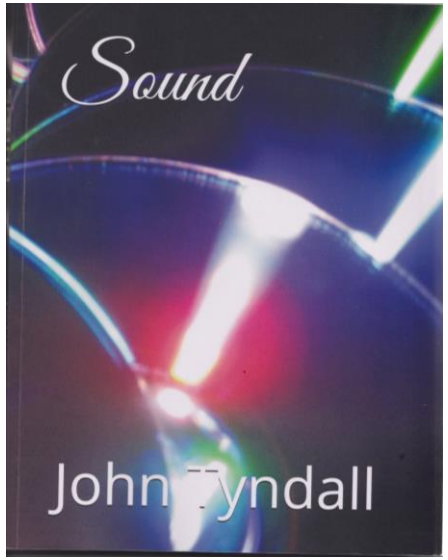
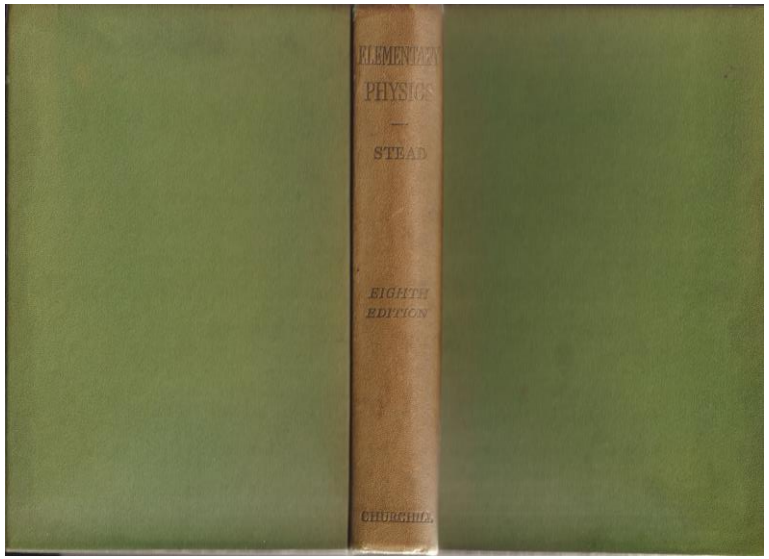
John Tyndall


Sound
John Tyndall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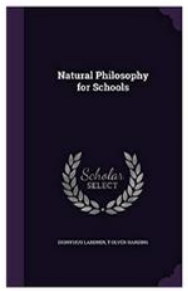
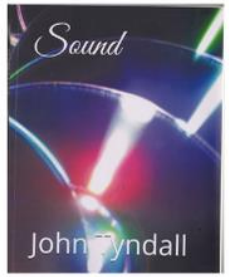


1865



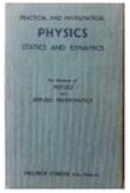
1875

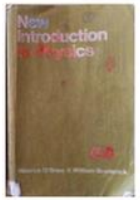
4 decades

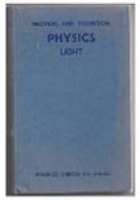
1906

LC Introduced

1924







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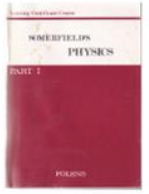
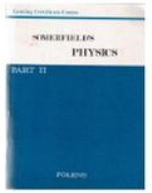
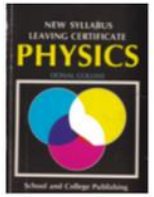
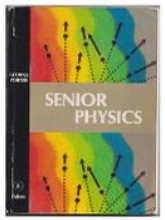
1962

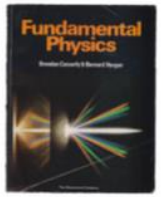




1972

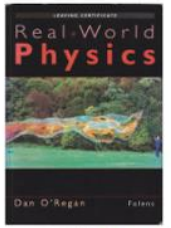


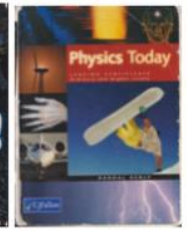




1984

Revised Course

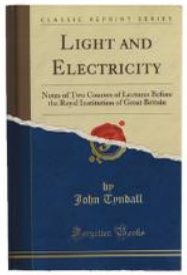




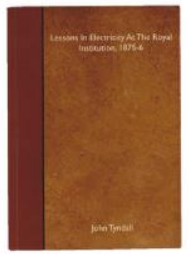
2000

Revised Course

1871

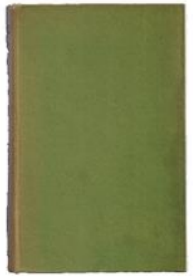


1876



1888

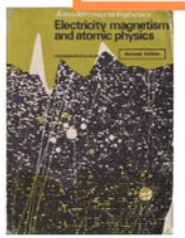
1924

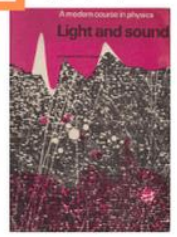


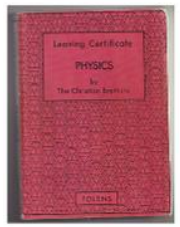
4 decades
(8 editions)

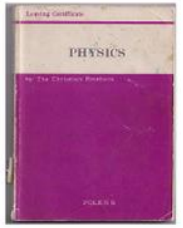
Revised Course

1971

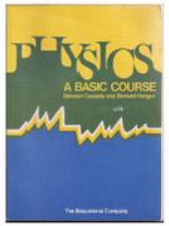




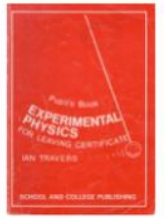




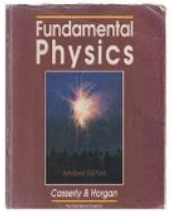
1981



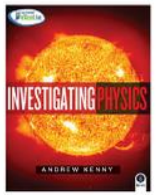
1987



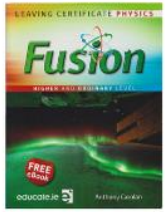
1990



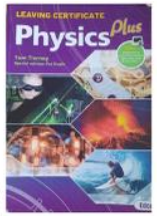
2010



2013



2014



What can we learn from this archive?

What's changed?

What's stayed the same?

Is there evidence of Lardner and Tyndall's ideas present in more recent textbooks?

Characteristics of Physics as a subject

- **Theoretical** and **experimental**
- **Multimodal** – demonstrations, experiments, mathematics, diagrams
- **Diagrams** - an integral part of subject and not an optional add-on. Impossible to communicate Physics concepts without visualising them
- Benefits from the **language of mathematics**, much like Law and Medicine benefit from Latin

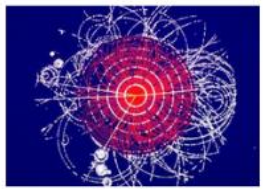
Physics as a Subject

Electricity in infancy

1895

1897

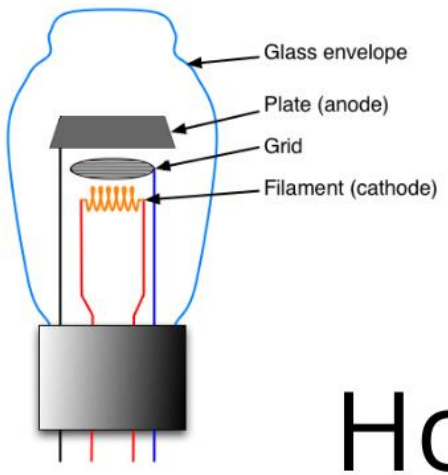
1932



Higgs-boson

1860

2022



How we experiment

Equipment has changed

Equipment has changed

Thermionic Valves

- Thermionic valves had not been conceived of in Lardner and Tyndall's time
- Had great significant in heyday of radio and TV
- Superseded by semi-conductor improvements

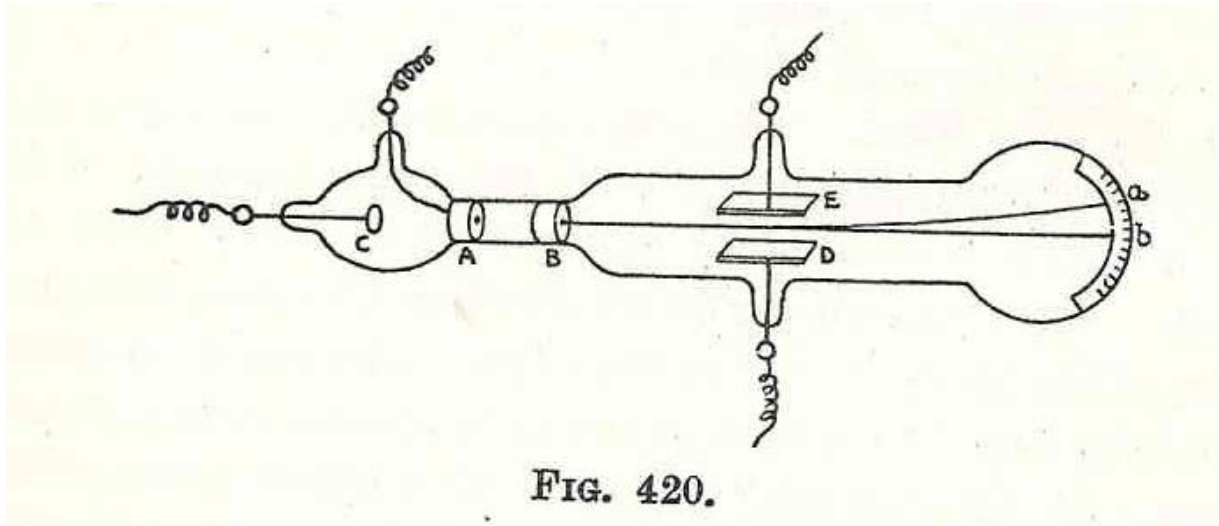
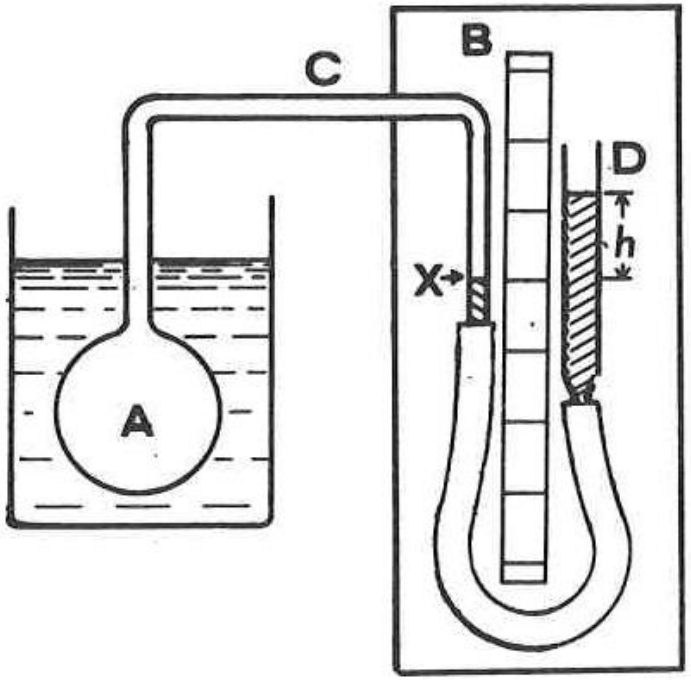


FIG. 420.

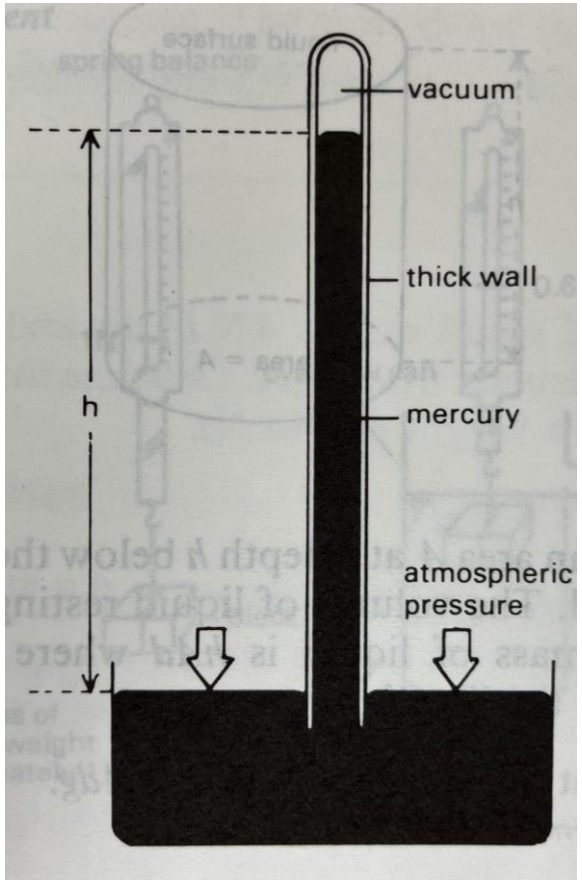
Thomson's e/m tube in Stead (1924)

Equipment has changed

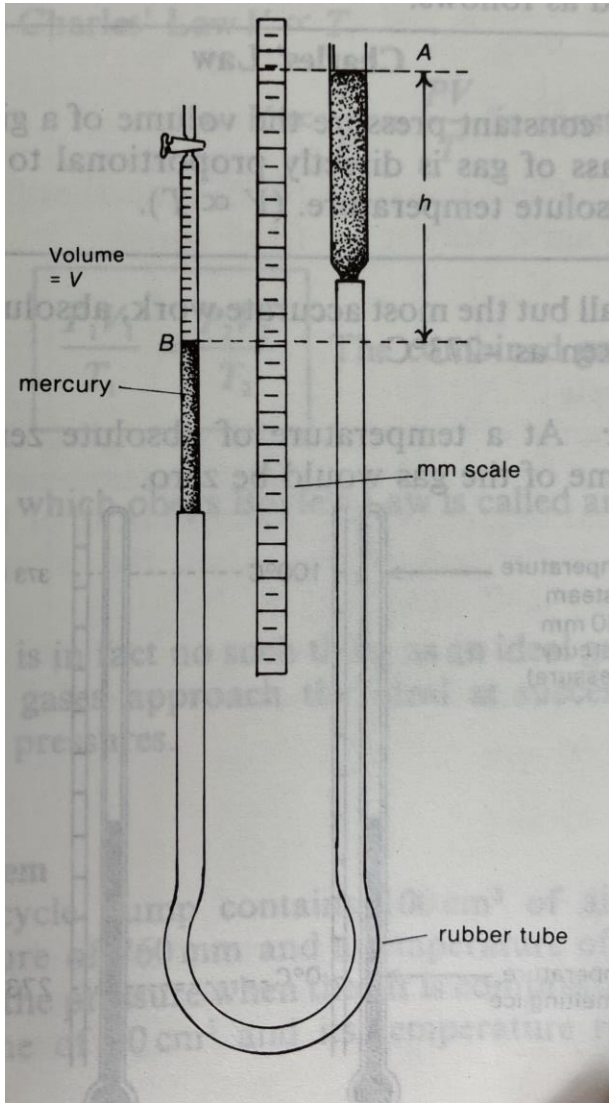
Use of Mercury



Christian Brothers (1971)
Constant volume gas thermometer



Casserly and Horgan (1984)
Barometer



Casserly and Horgan (1984)
Boyle's law

Equipment has changed

Use of Mercury

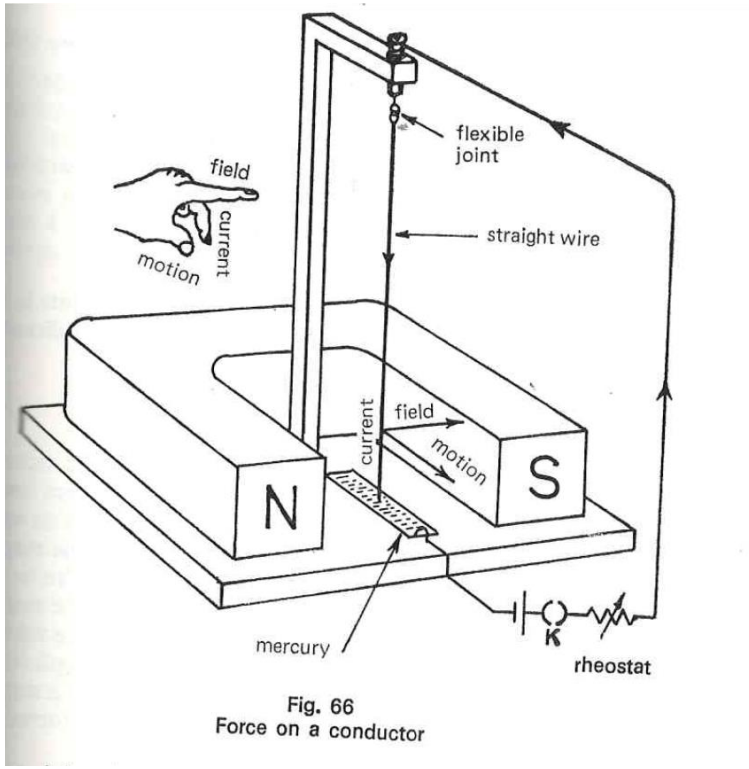
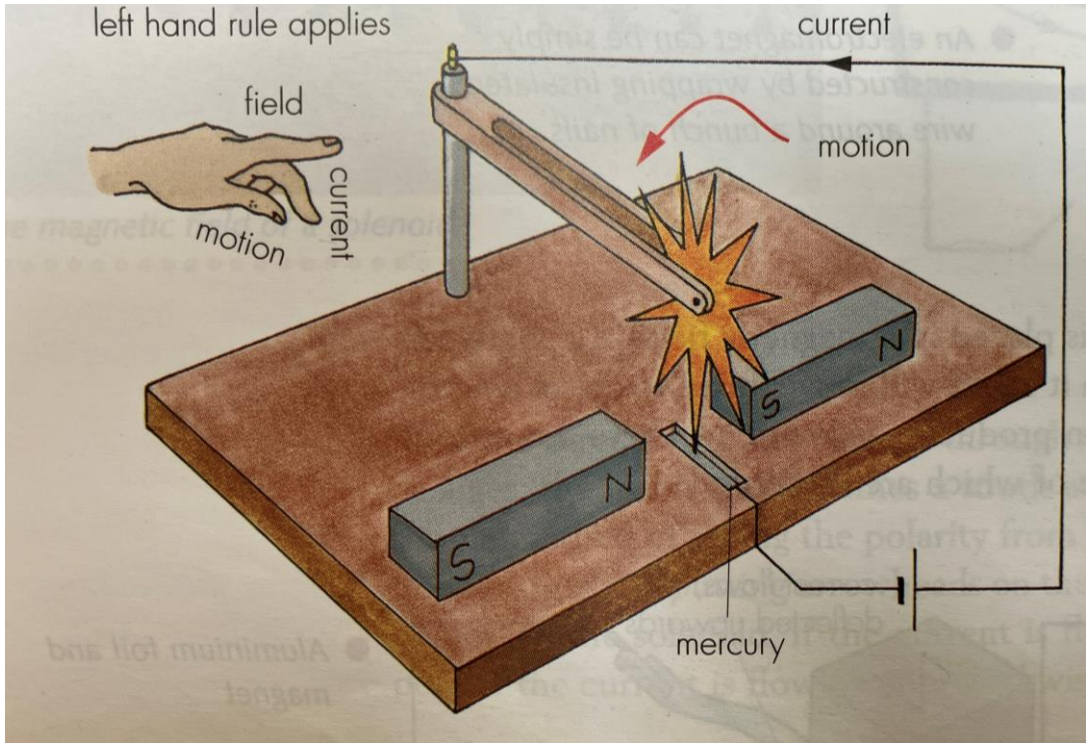


Fig. 66
Force on a conductor

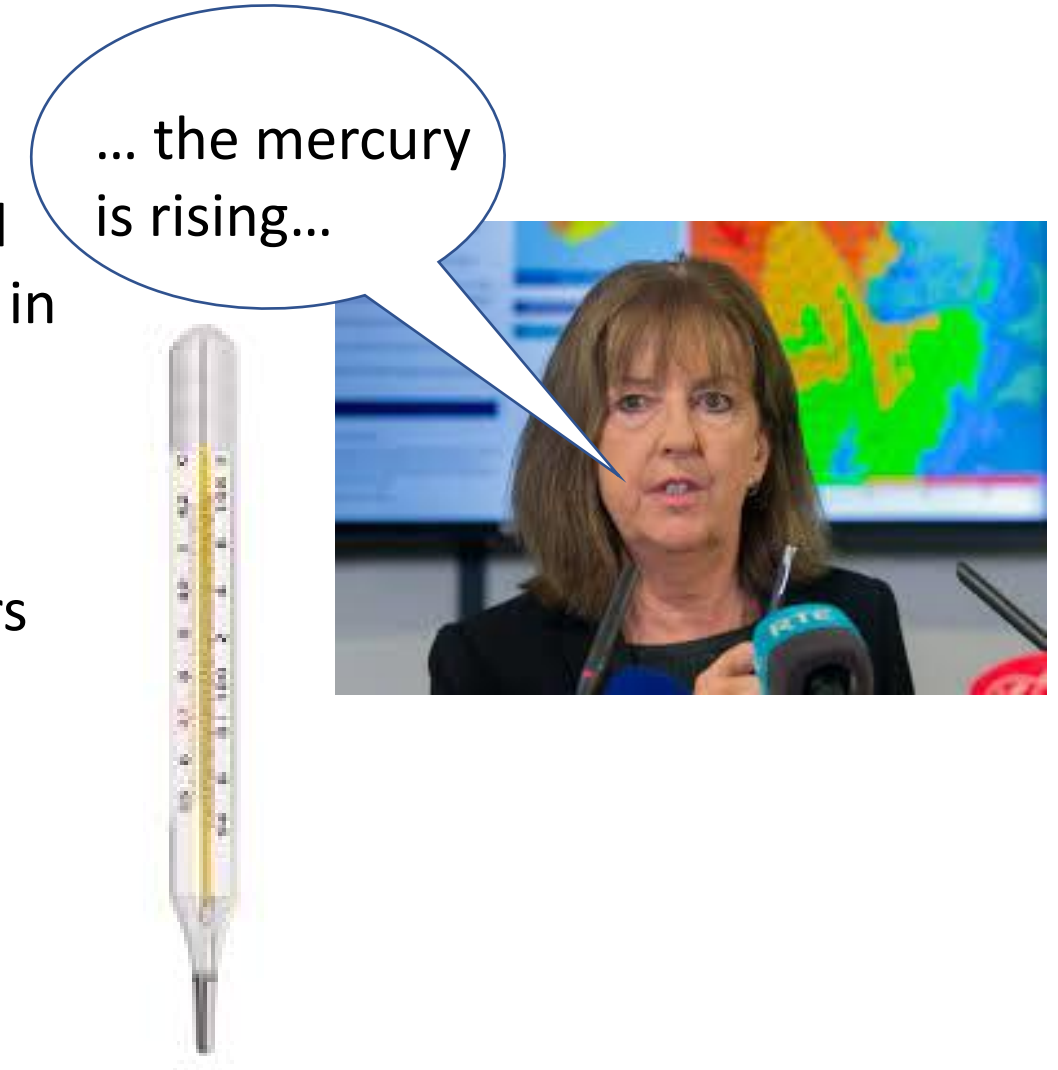
O'Donoghue (1971)
Faraday's motor



Henly (2000)
Faraday's motor

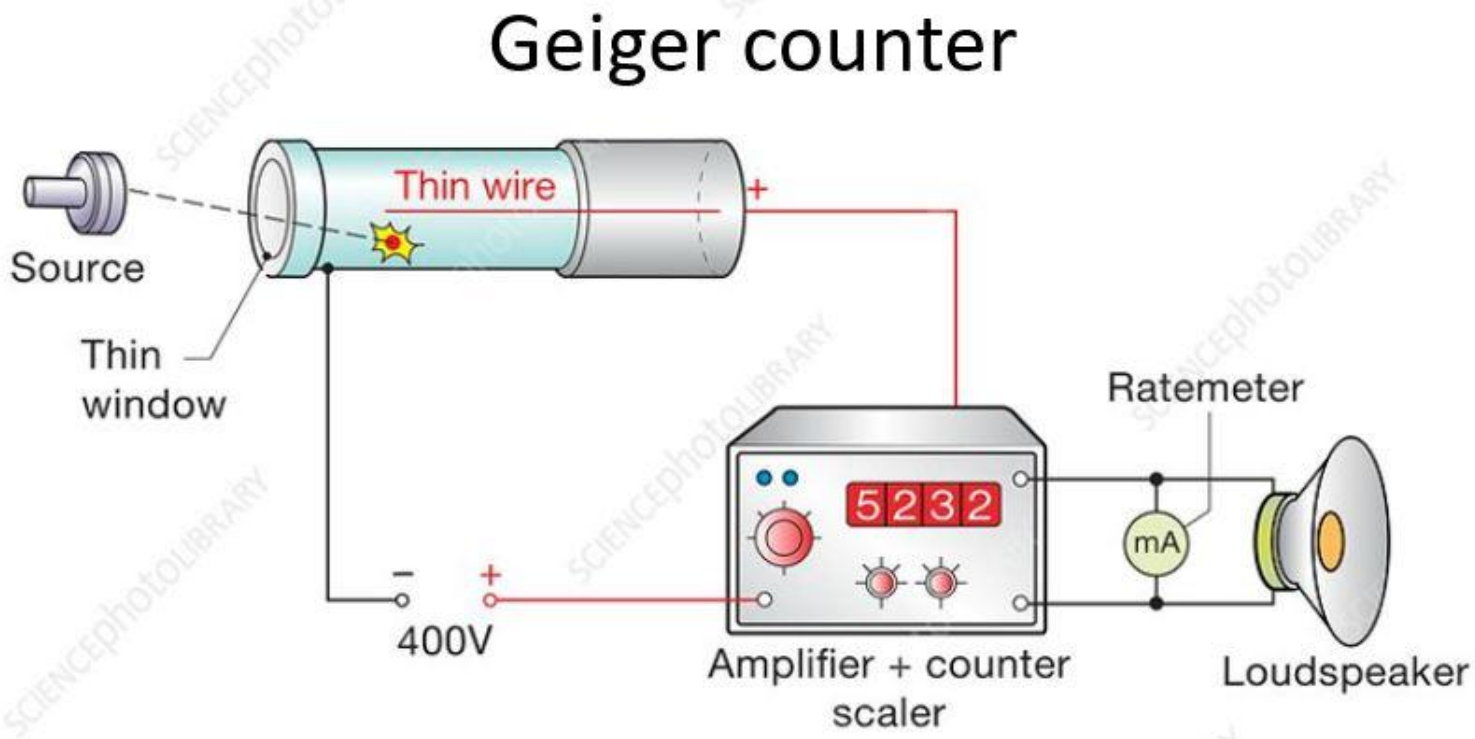
Toxic nature of Mercury

- 2001: Full page in safety guidelines issued by the Minister for Education on mercury in the classroom
- 2002: teacher guidelines stated it was appropriate to use mercury thermometers
- By 2011 schools were advised not to use mercury in any manner.



Equipment has changed

Use of Radiation



- 2002: teacher guidelines states that the **careful** use of ionising radiation is **essential**
- 2013: schools were told to surrender all radioactive sources and a disposal program was funded.

Characteristics of Physics textbooks

Experiments

Demonstrations

Representation of Women

Diagrams

Mathematics

Derivations

Diagrams

Evocative of their era and are constantly changing

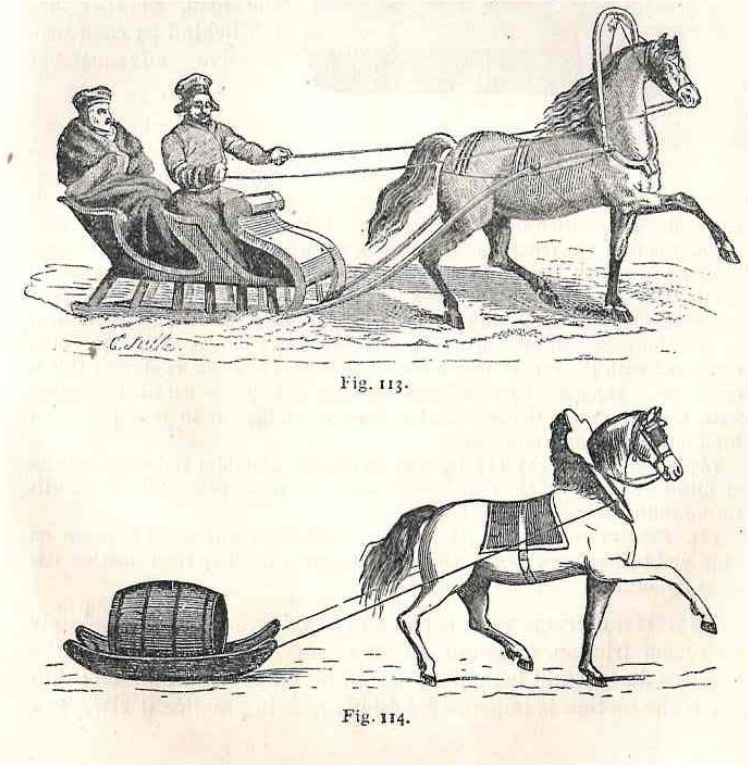
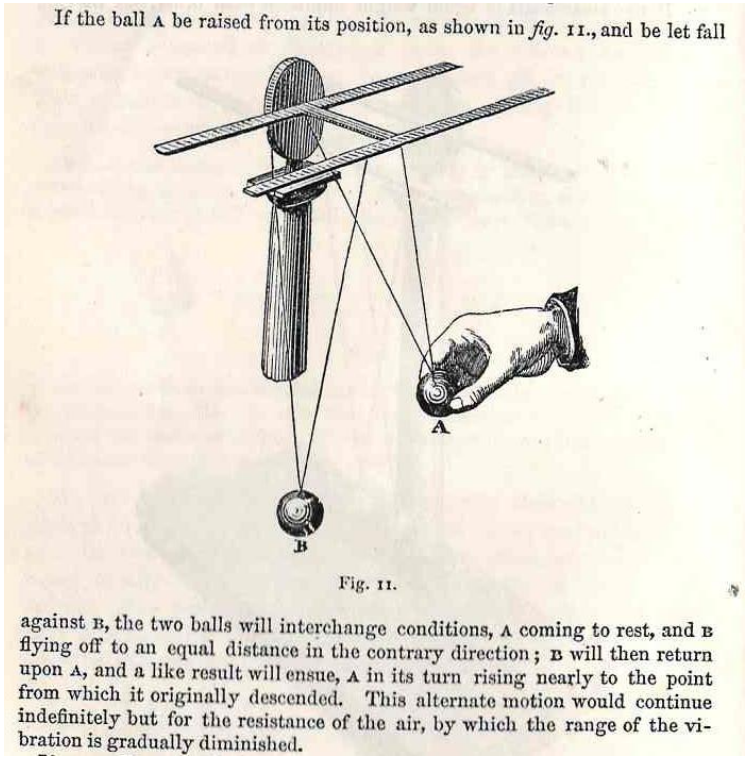


Fig. 113.

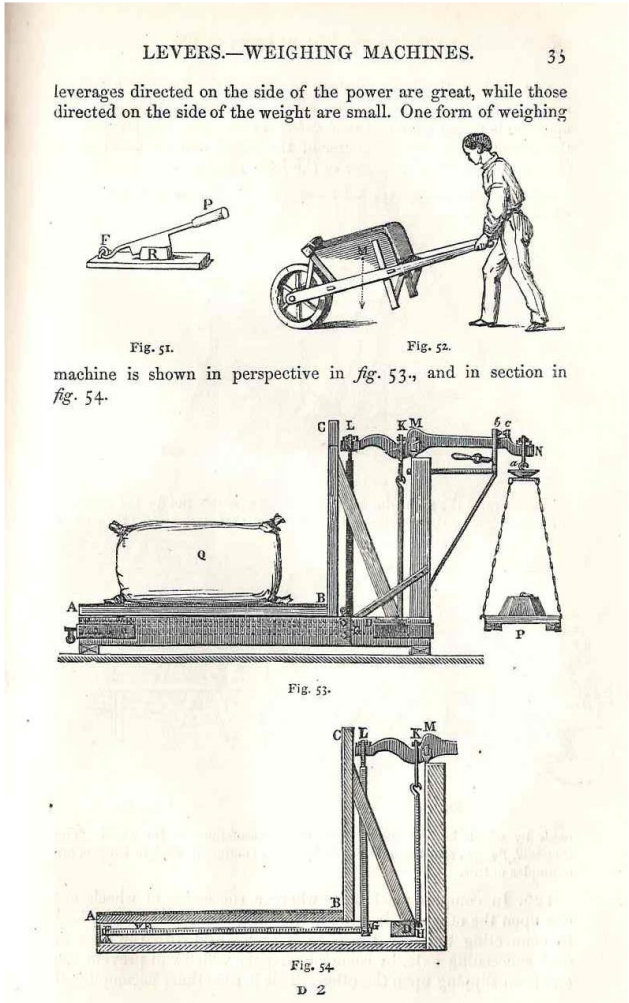
Fig. 114.



If the ball A be raised from its position, as shown in *fig.* 11., and be let fall

Fig. 11.

against B, the two balls will interchange conditions, A coming to rest, and B flying off to an equal distance in the contrary direction; B will then return upon A, and a like result will ensue, A in its turn rising nearly to the point from which it originally descended. This alternate motion would continue indefinitely but for the resistance of the air, by which the range of the vibration is gradually diminished.



LEVERS.—WEIGHING MACHINES. 33

leverages directed on the side of the power are great, while those directed on the side of the weight are small. One form of weighing

Fig. 51. Fig. 52.

machine is shown in perspective in *fig.* 53., and in section in *fig.* 54.

Fig. 53.

Fig. 54.

D 2

Lardner (1865)

Diagrams

Often hand-drawn and hugely detailed

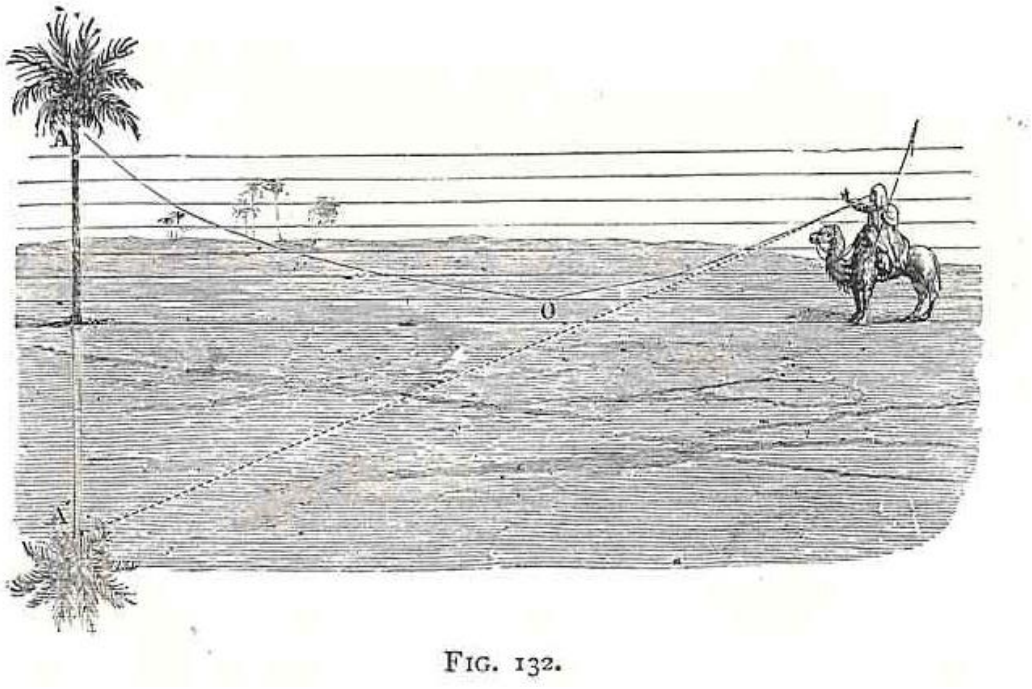


FIG. 132.

Mirage (Lardner, 1865)

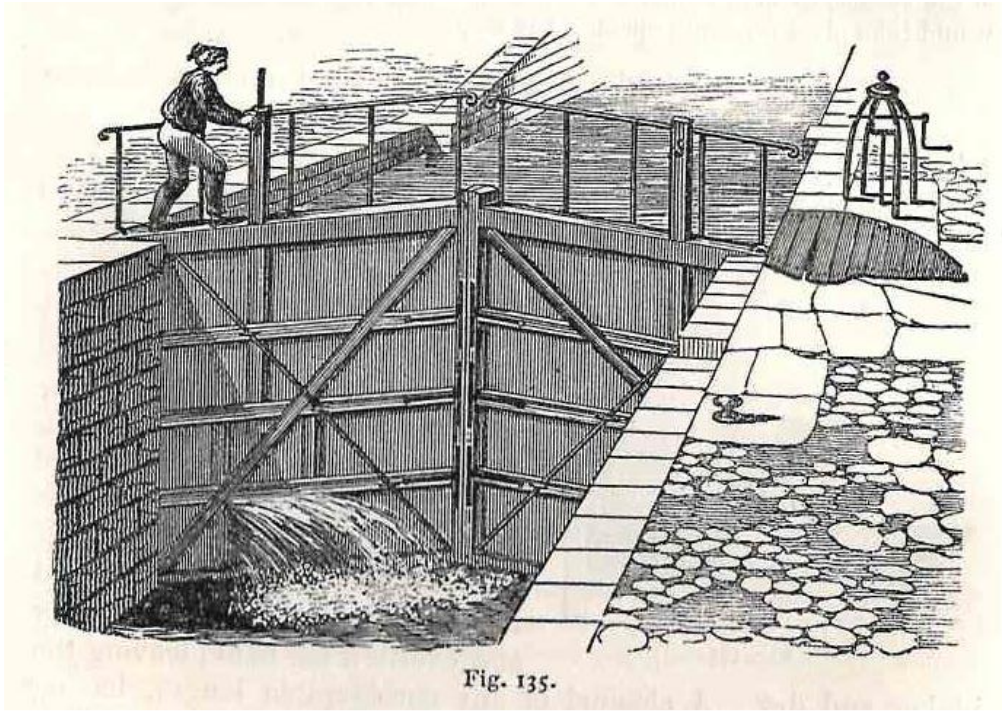
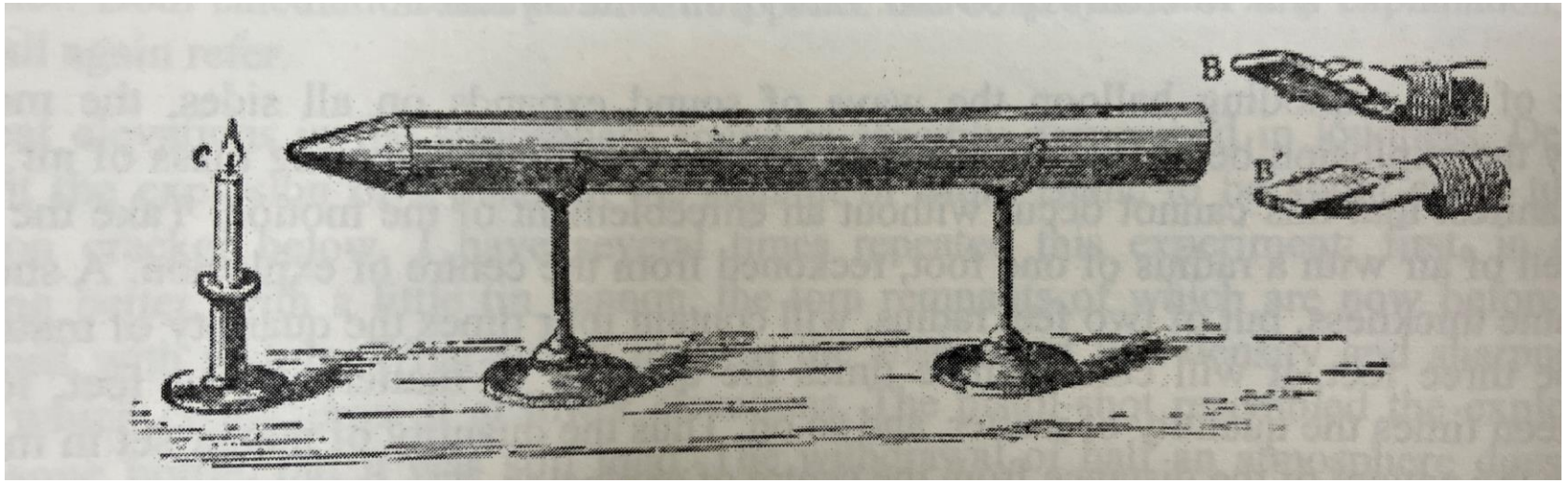


Fig. 135.

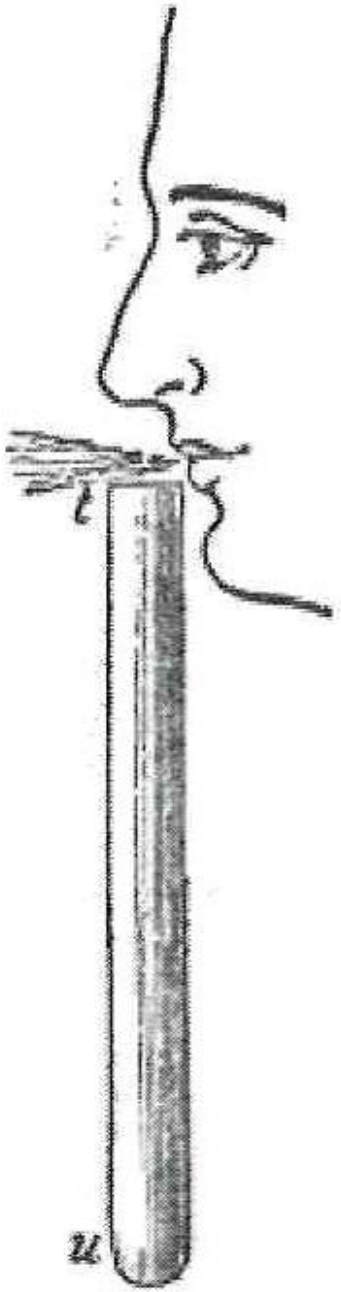
Water Pressure (Lardner, 1865)

Diagrams

Great power in a well-drawn diagram



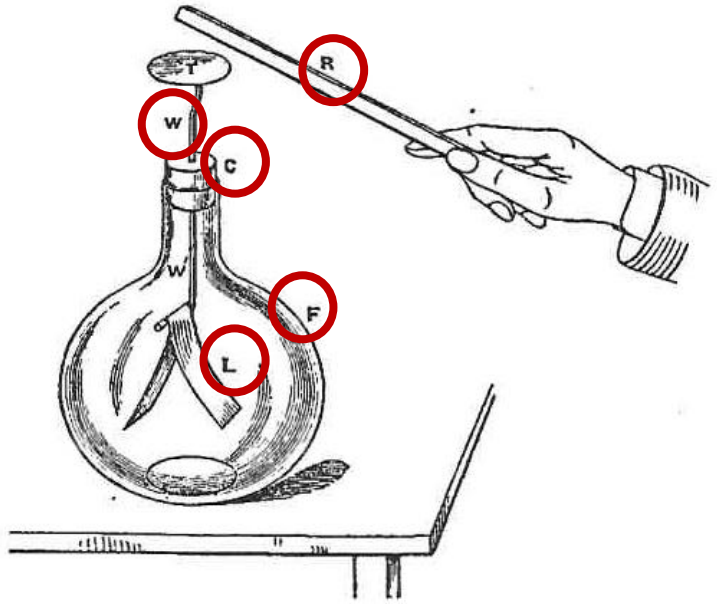
Tyndall (1871)



Diagrams

Labelling with letters that enabled the explanation in the text

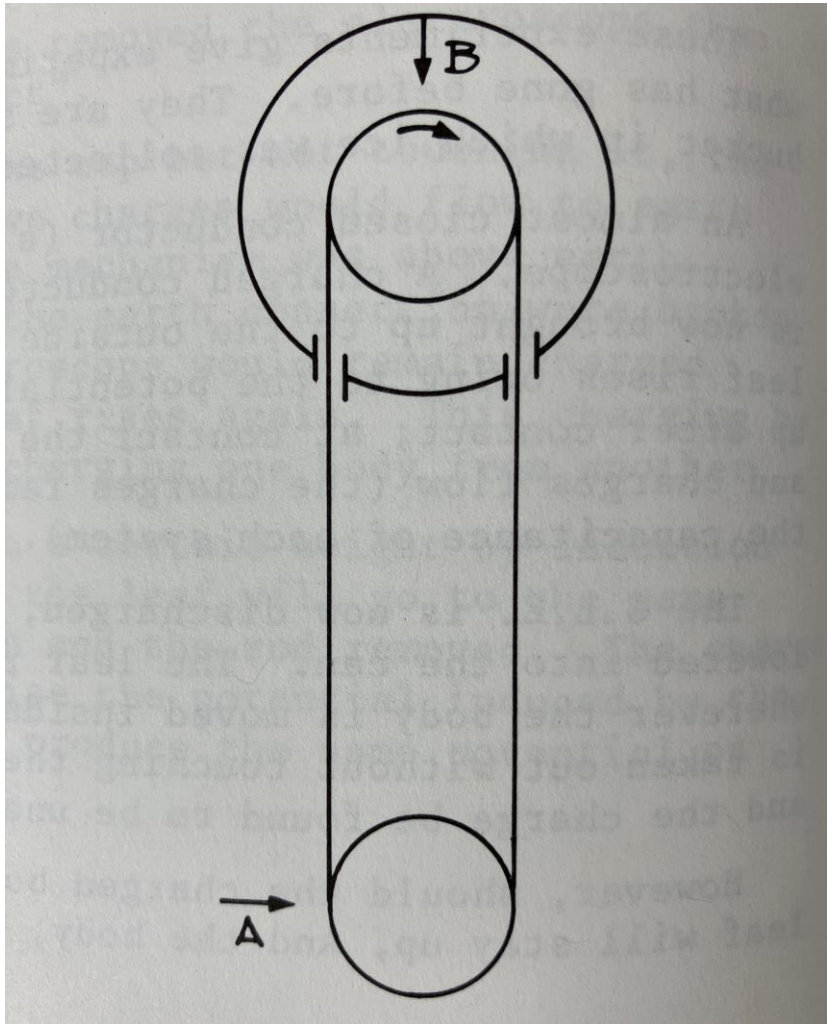
for sixpence, or at the most a shilling. Find a cork, C, which fits the flask; pass a wire, W, through the cork and bend it near one end at a right angle. Stick by sealing-wax upon the other end of the wire a little plate of tin or sheet-zinc, T, about two inches in diameter. Attach also by means of wax to the bent arm, which ought to be about three quarters of an inch long, two strips, L, of the Dutch metal, about three inches long and from half an inch to three quarters of an inch wide. The strips will hang down face to face, in contact with each other. In all cases you must be careful so to use your wax as not to interrupt the metallic connection of the various parts of your apparatus, which we will name an *electroscope*. Gold leaf, instead of



Tyndall (1871)
Electrostatic repulsion

Diagrams

Power of an uncluttered diagram

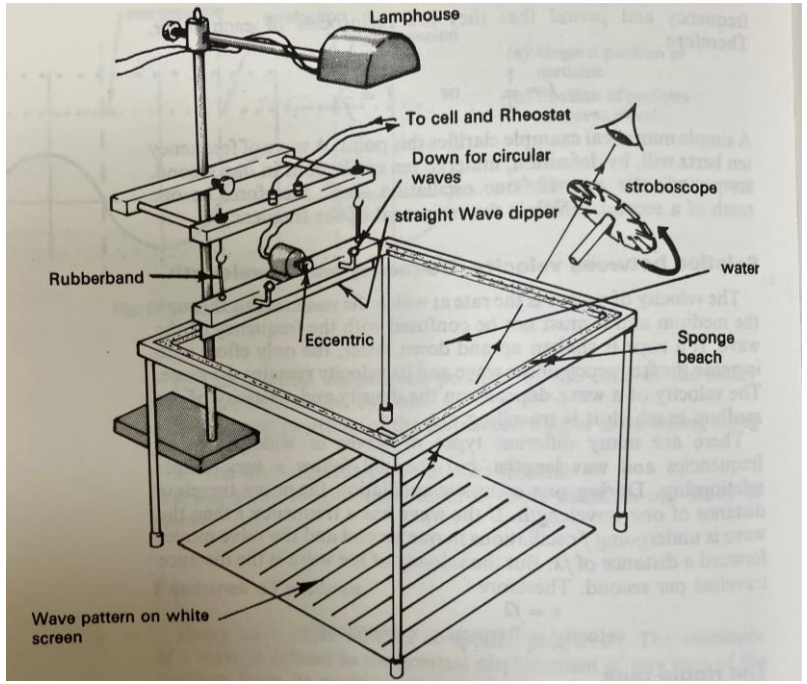


Sommerfield (1972)

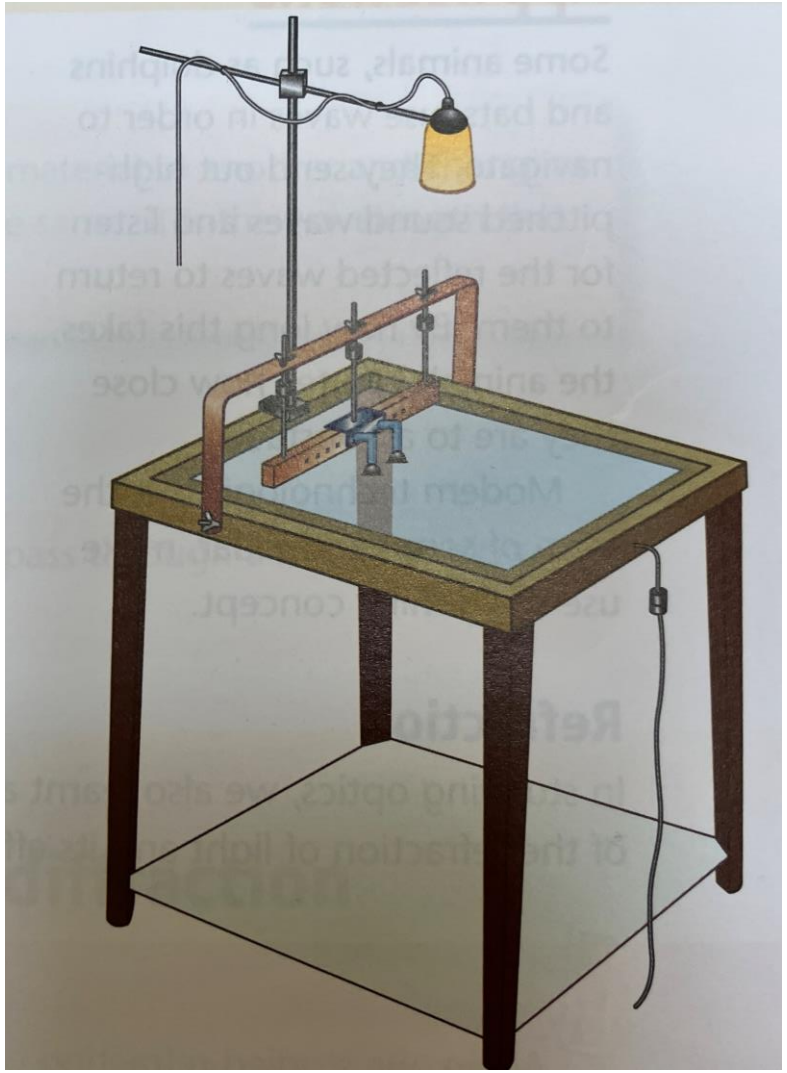
Van de Graff generator

Diagrams

Diagrams may include lots of information, or be quite simplistic



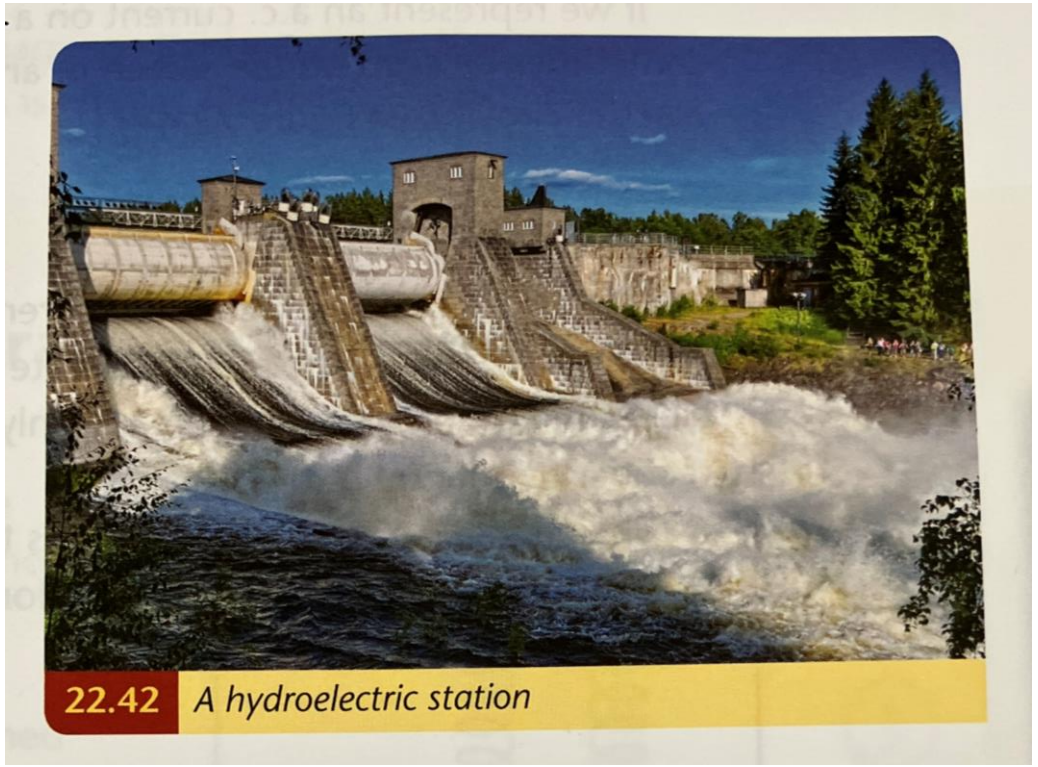
O'Donohue (1971)



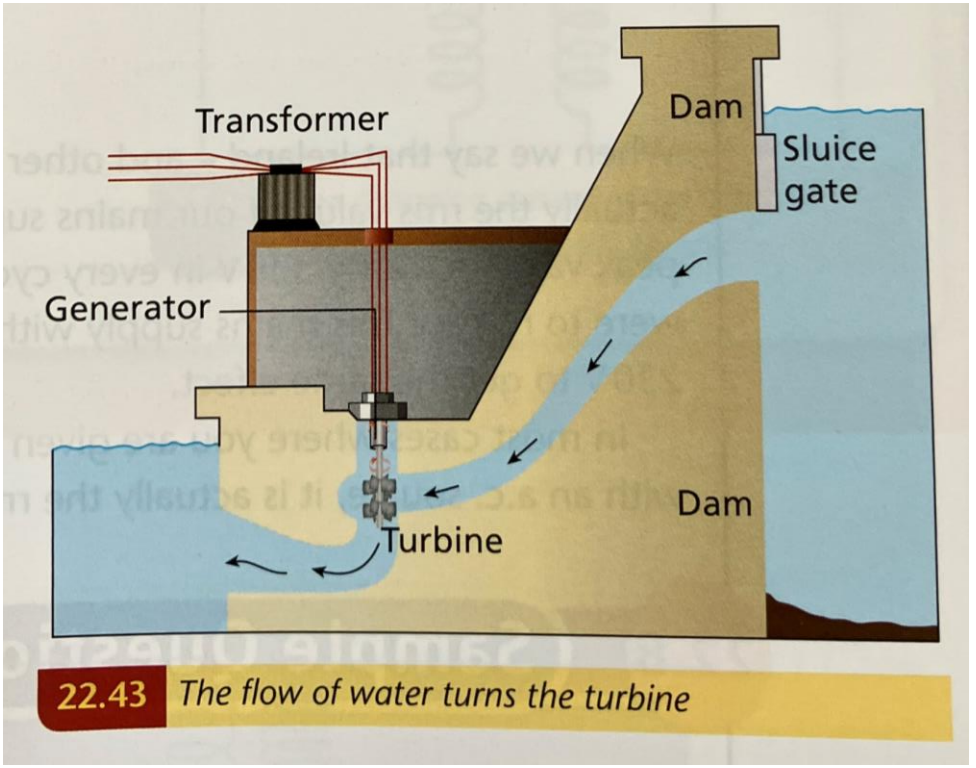
Tierney (2014)

Diagrams

An accompanying photo can enhance the diagram



22.42 *A hydroelectric station*



22.43 *The flow of water turns the turbine*

Tierney (2014)

Diagrams

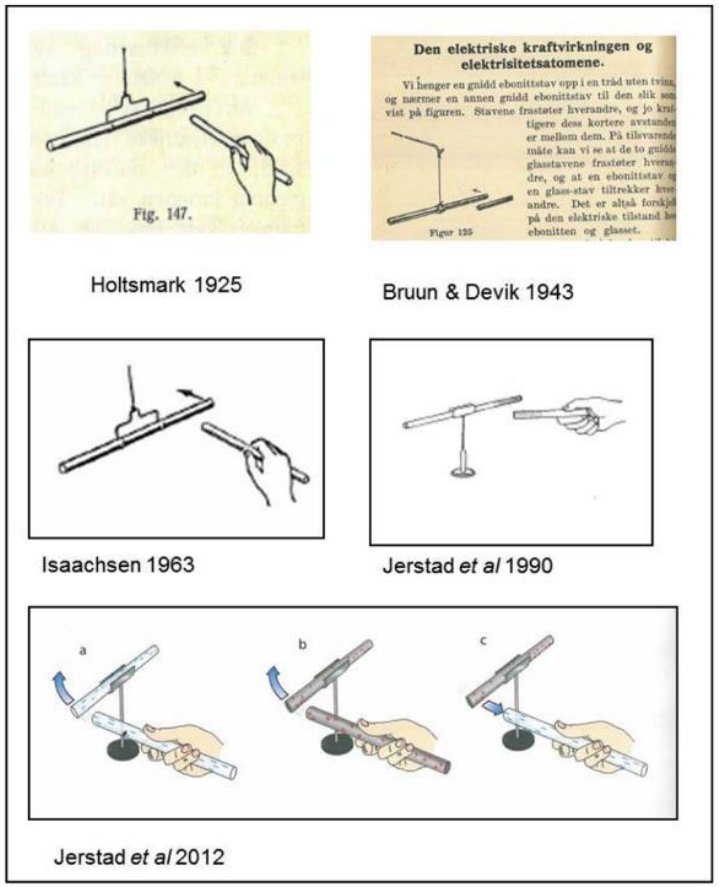
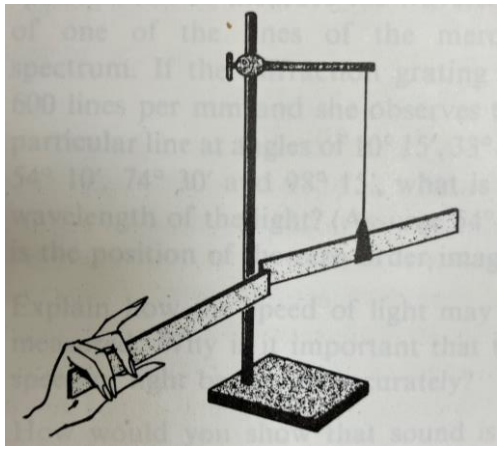
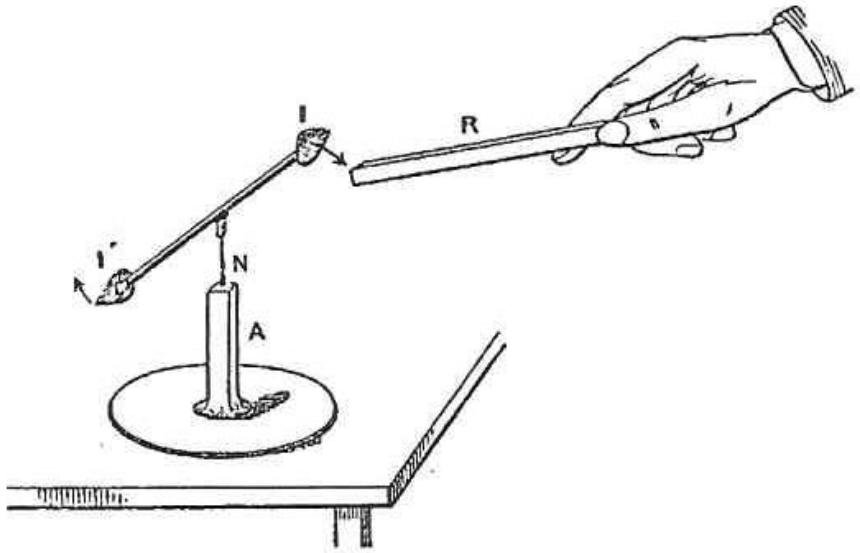


Figure 1. The stability of images in physics textbooks.

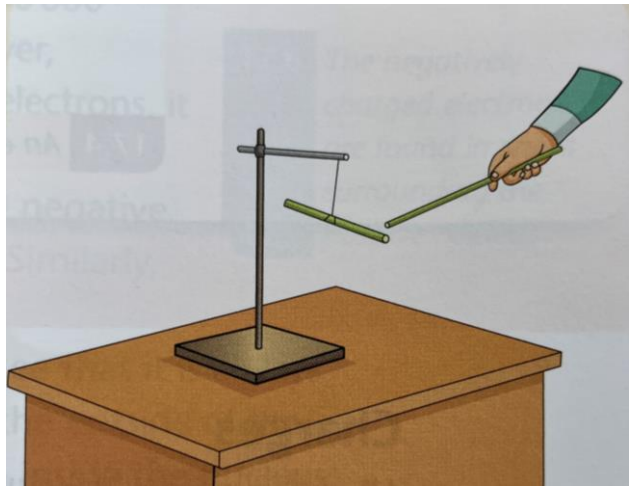
Bungum (2013)



Porter (1984)



Tyndall (1871)



Tierney (2014)

Diagrams

Advances in colour printing

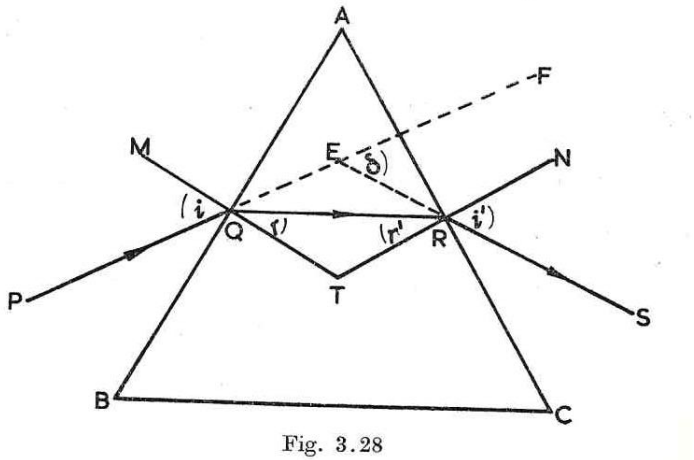
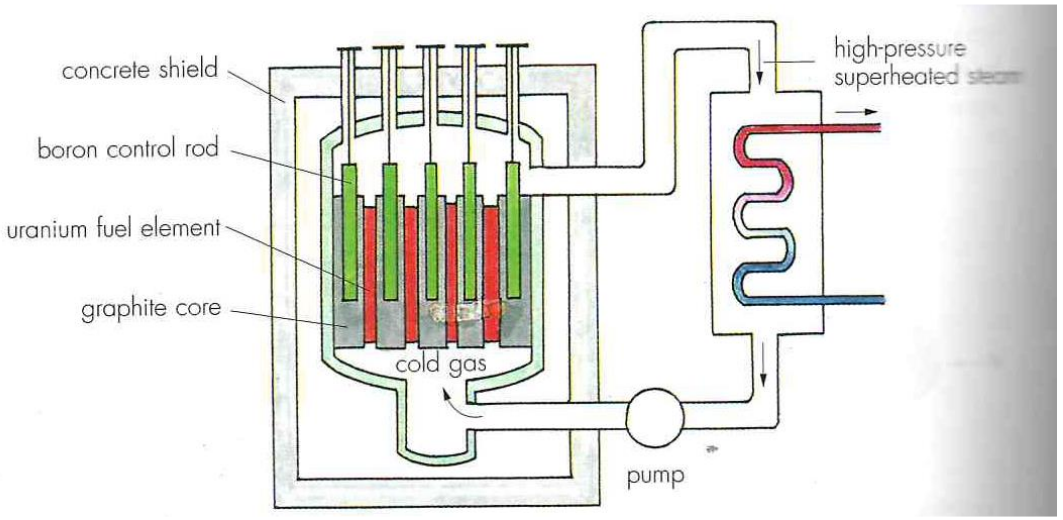
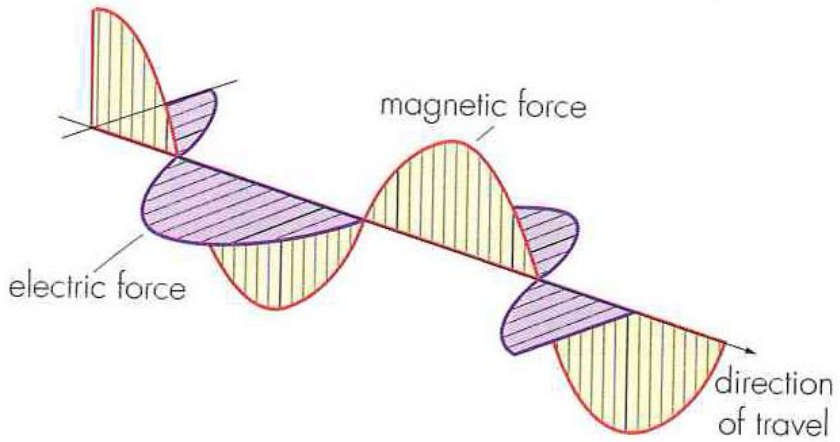


Fig. 3.28

O'Brien (1962)

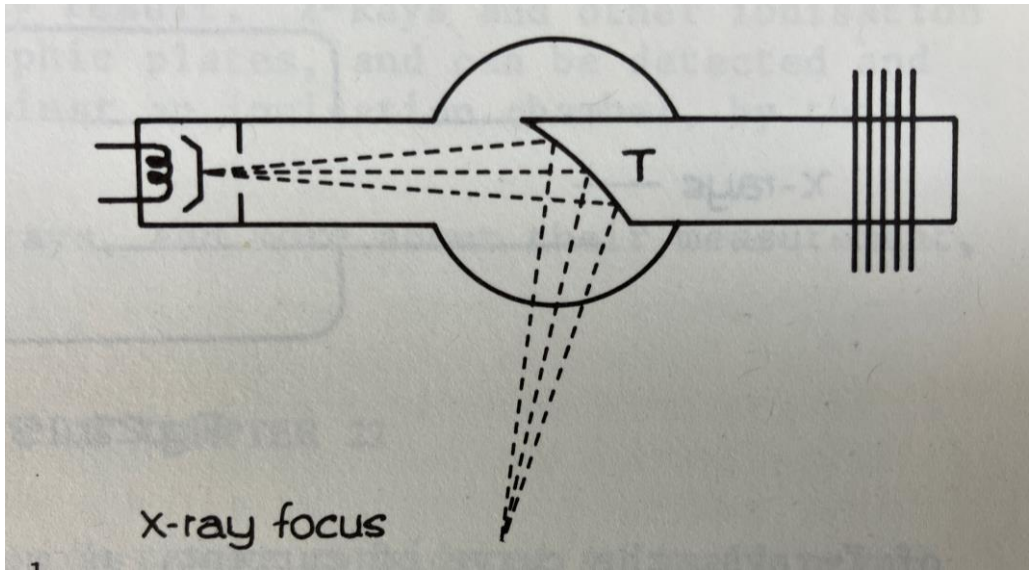




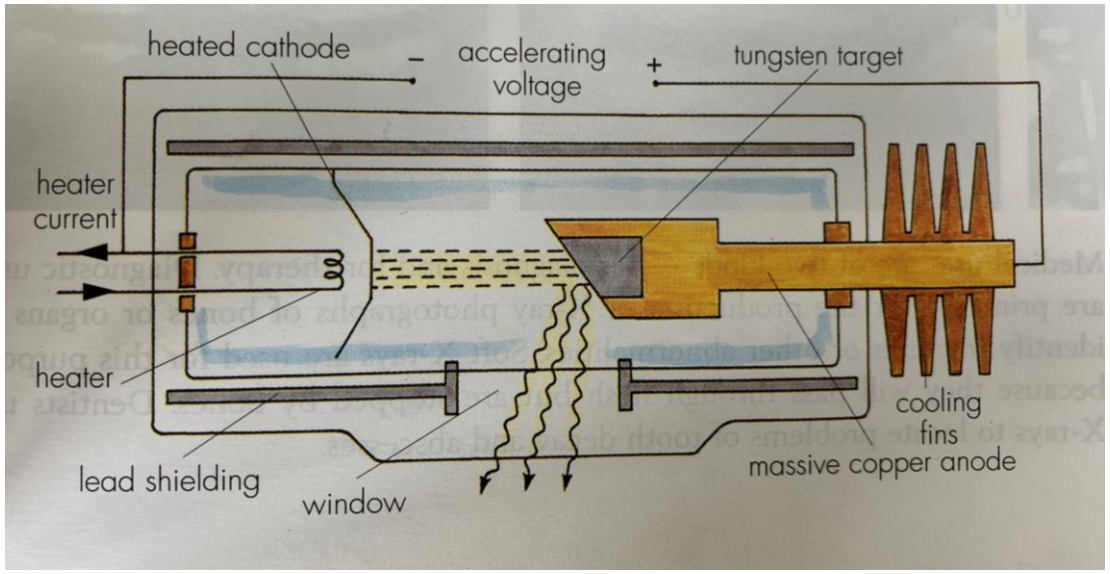
Henly (2000)

Diagrams

Advances in colour printing – production of x-rays



Sommerfield (1972)



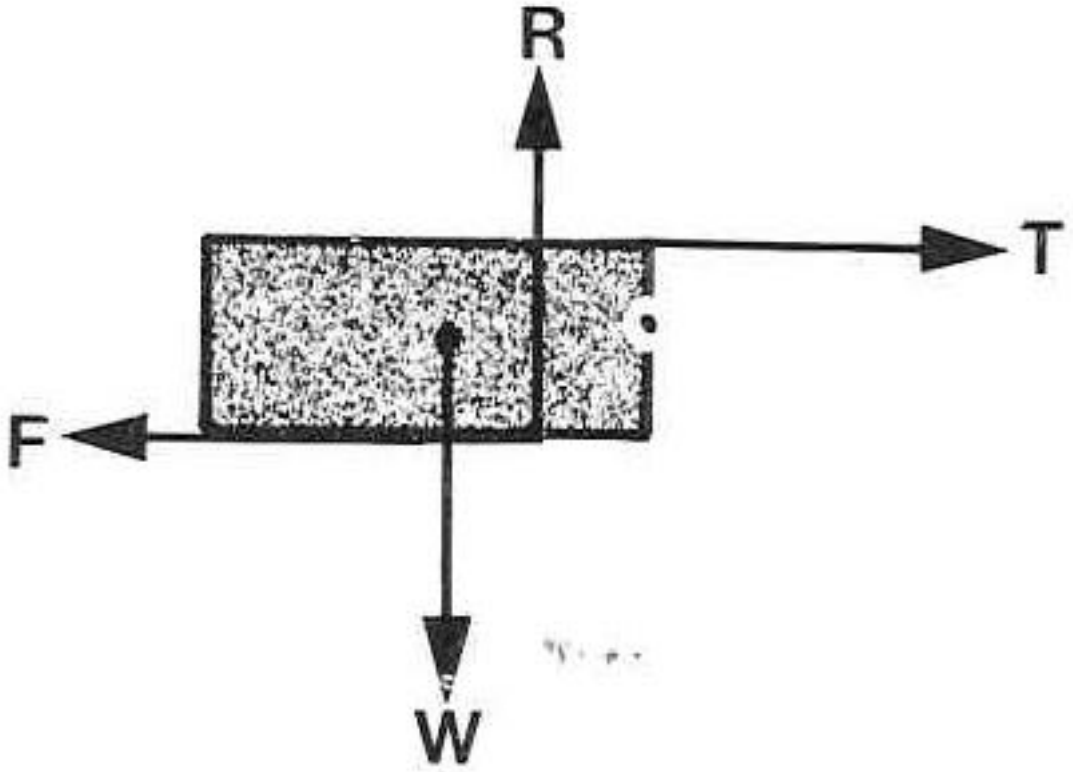
Henly (2000)

Diagrams

Diagrams have many varied uses

Construction of a Free Body Diagram: problem solving

Means of setting up equations



Porter (1984)

Mathematics – language of communication

- A shorthand for making concise and precise statements
- Mathematical operations are invaluable to aid reasoning
- Went in and out of fashion depending on examinations and the inclination of the author

Mathematics – language of communication

- Larder and Tyndall made minimal reference to mathematics
- Ganot – maths written in words
- Peak in 1960s and 1970s before…

Let LI be now parallel to AB, the angle r is then equal to the critical angle l of the prism, because it has its maximum value. Further, the angle EPK, the exterior angle of the triangle IPE, is equal to $r + i''$; but the angles EPK and A are equal, because the sides which contain them are at right angles to each other, and therefore $A = r + i''$; therefore also $A = l + i''$, for in this case $r = l$. Hence, if $A = 2l$ or is $> 2l$, we shall have $i' = l$ or $> l$, and therefore the ray would not emerge at the second face, but would be parallel to AC or would undergo internal reflection, and emerge at a third face, BC. This would be much more the case with rays whose incident angle is less than BIN, because we have already seen that i' would continually increase. Thus in the case in which the refracting angle of a prism is equal to $2l$ or is greater, no luminous ray could pass through the faces of the refracting angle.

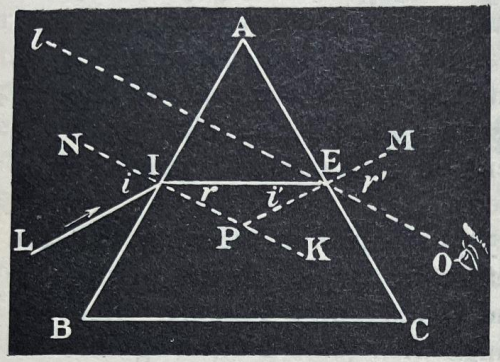
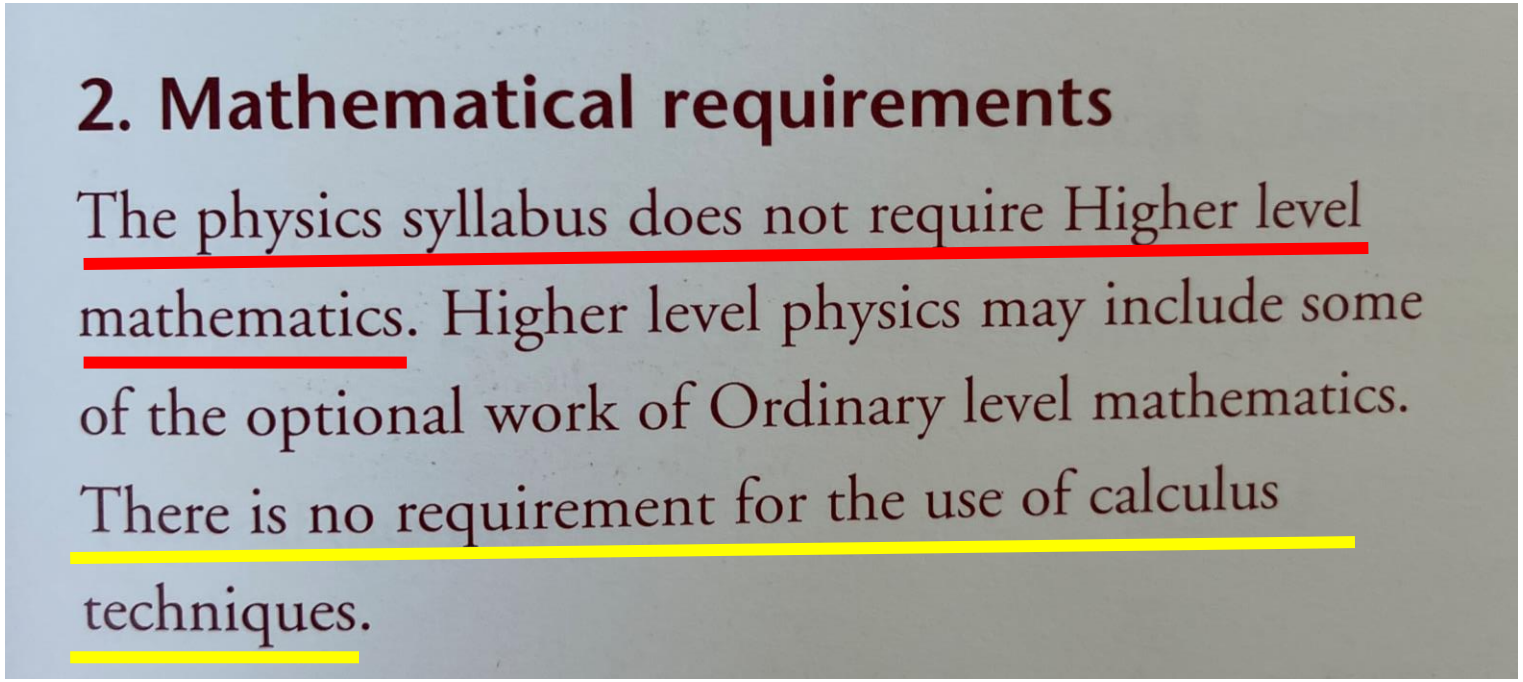


Fig. 531

As the critical angle of glass is 41° 48′, and twice this angle is less than 90°, objects cannot be seen through a glass prism whose refracting angle is a right angle. As the critical angle of water is 48° 35′, light could pass through a hollow right-angled prism formed of three glass plates and filled with water.

Ganot (1906)

Mathematics – Syllabus



2. Mathematical requirements

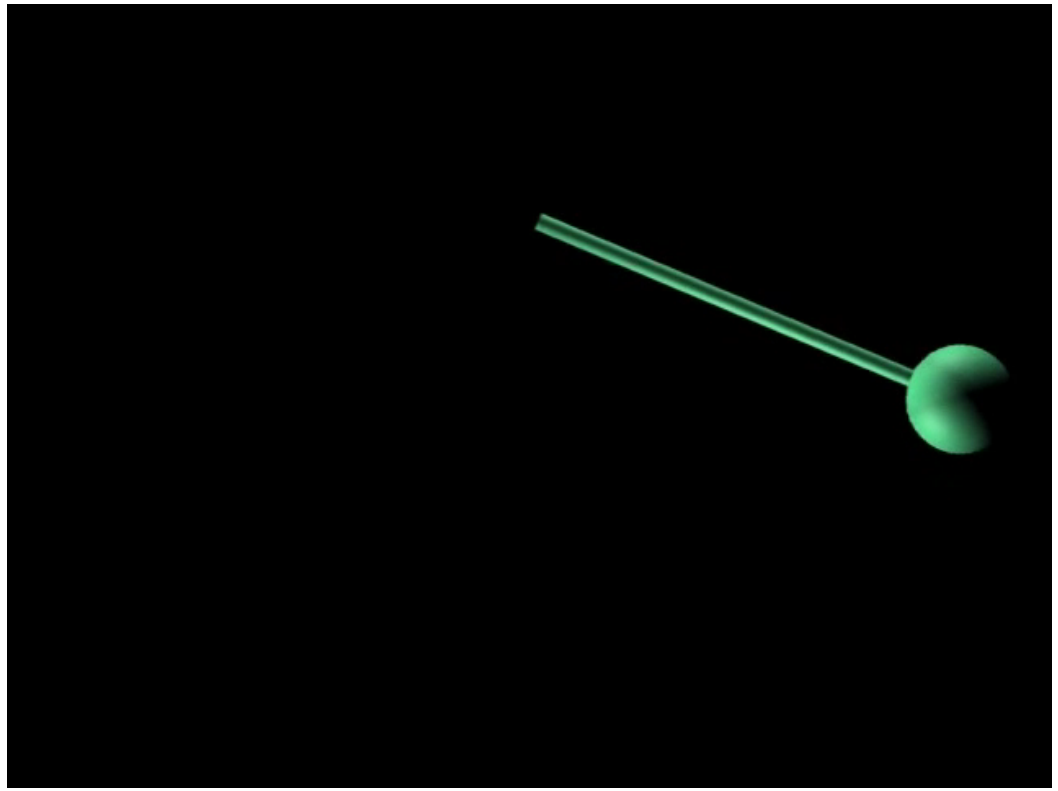
The physics syllabus does not require Higher level mathematics. Higher level physics may include some of the optional work of Ordinary level mathematics. There is no requirement for the use of calculus techniques.

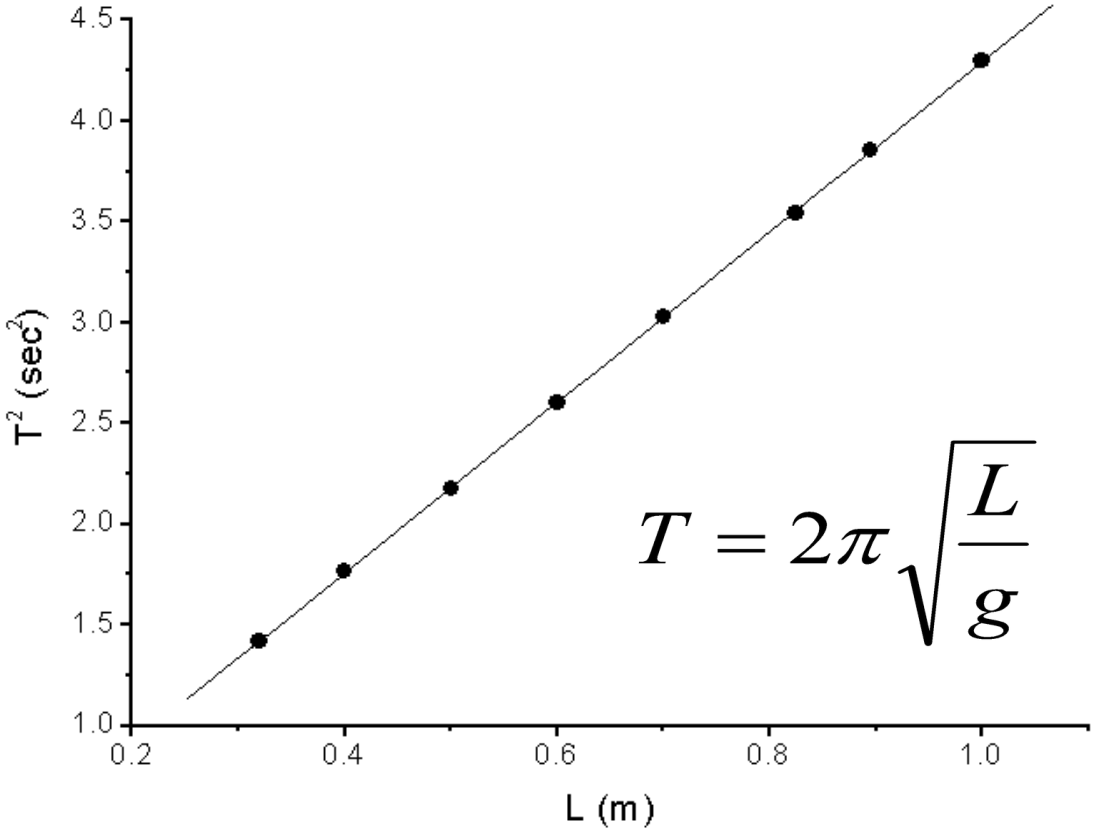
$$\mathcal{E} = -\frac{d\phi}{dt}$$

$$\frac{dN}{dt} = -\lambda N$$

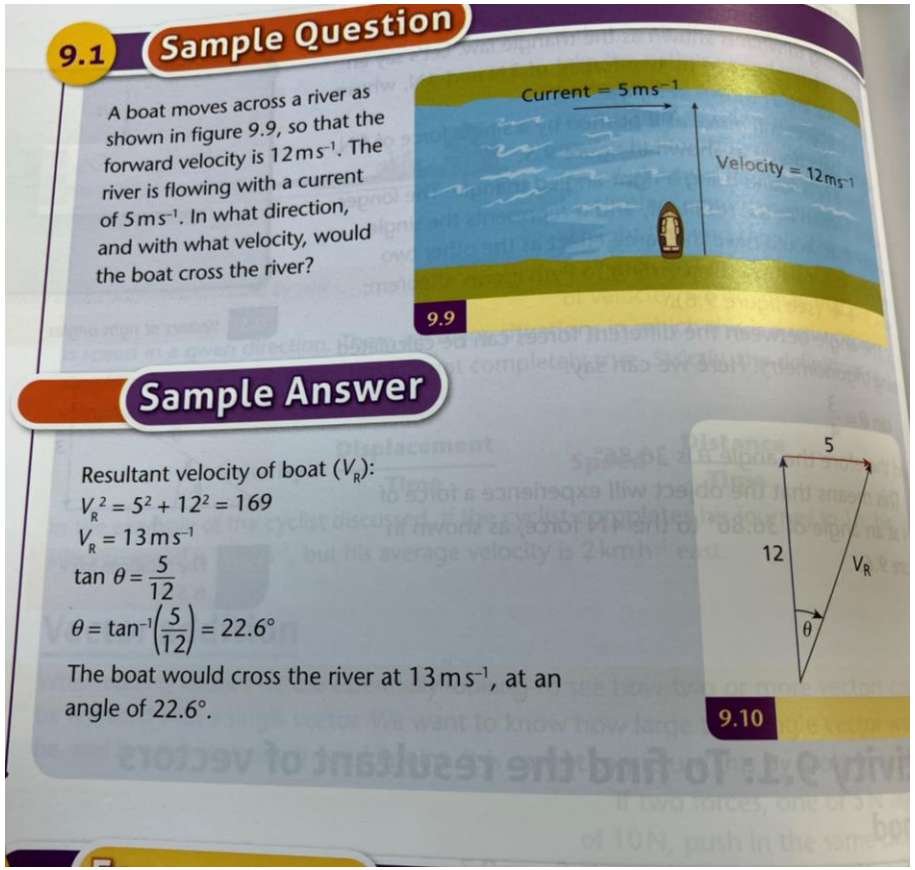
Syllabus (2000)

Mathematics – e.g. the Pendulum





Mathematics – Worked Examples



9.1 Sample Question

A boat moves across a river as shown in figure 9.9, so that the forward velocity is $12\,m\,s^{-1}$. The river is flowing with a current of $5\,m\,s^{-1}$. In what direction, and with what velocity, would the boat cross the river?

9.9

Sample Answer

Resultant velocity of boat (V_R):

$V_R^2 = 5^2 + 12^2 = 169$

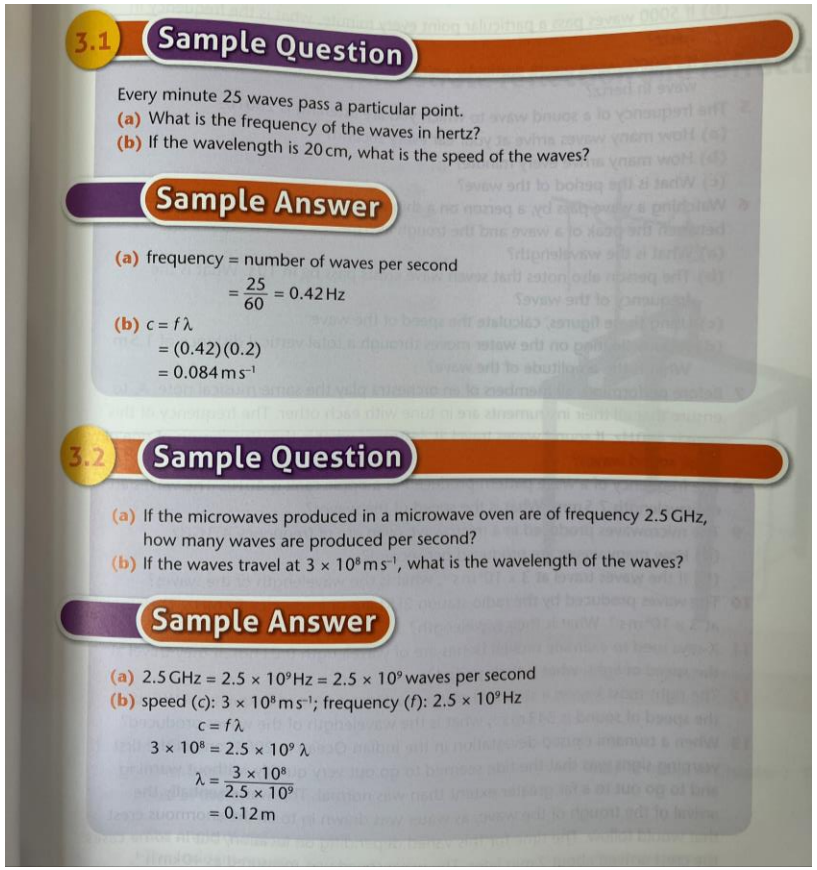
$V_R = 13\,m\,s^{-1}$

$\tan\theta = \frac{5}{12}$

$\theta = \tan^{-1}\left(\frac{5}{12}\right) = 22.6°$

The boat would cross the river at $13\,m\,s^{-1}$, at an angle of 22.6°.

9.10



3.1 Sample Question

Every minute 25 waves pass a particular point.

(a) What is the frequency of the waves in hertz?

(b) If the wavelength is 20 cm, what is the speed of the waves?

Sample Answer

(a) frequency = number of waves per second

$= \frac{25}{60} = 0.42\,Hz$

(b) $c = f\lambda$

$= (0.42)(0.2)$

$= 0.084\,m\,s^{-1}$

3.2 Sample Question

(a) If the microwaves produced in a microwave oven are of frequency 2.5 GHz, how many waves are produced per second?

(b) If the waves travel at $3 \times 10^8\,m\,s^{-1}$, what is the wavelength of the waves?

Sample Answer

(a) $2.5\,GHz = 2.5 \times 10^9\,Hz = 2.5 \times 10^9$ waves per second

(b) speed (c): $3 \times 10^8\,m\,s^{-1}$; frequency (f): $2.5 \times 10^9\,Hz$

$c = f\lambda$

$3 \times 10^8 = 2.5 \times 10^9\,\lambda$

$\lambda = \frac{3 \times 10^8}{2.5 \times 10^9}$

$= 0.12\,m$

Tierney (2014)

Derivations

- Derivations are producing mathematical evidence that a law is true
- Inclusion of derivations varied through the years
- Some authors placed strong emphasis on rigor and included many derivations
- Others stated an equation without derivation (lest the emphasis on mathematics deter students)
- O'Donoghue's (1971): derivation of a lens formula showing the extensive use of the geometry of Euclid

Consider the triangles *bao* and *mai*

$$\angle bao = \angle mai$$
$$\angle boa = \angle mia$$

Therefore, the triangles *bao* and *mai* are similar

$$\therefore \quad \frac{|im|}{|ob|} = \frac{|ai|}{|ao|} = \frac{v}{u}$$

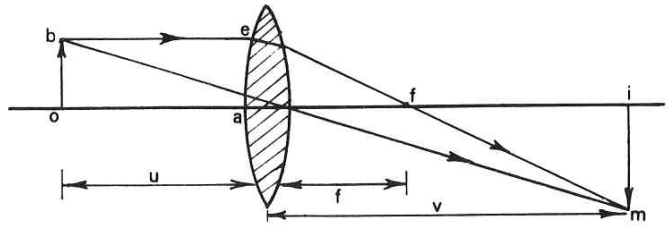


Fig. 112 Distance Formula for Convex Lens, Image Real

Consider the triangles *efa* and *mfi*

$$\angle efa = \angle mfi$$
$$\angle eaf = \angle mif$$

Therefore, the triangles *efa* and *mfi* are similar.

$$\therefore \quad \frac{|im|}{|ea|} = \frac{|fi|}{|af|} = \frac{|ai| - |af|}{|af|} = \frac{v - f}{f}$$

Since $|bo| = |ea|$

$$\frac{|im|}{|bo|} = \frac{|im|}{|ea|}$$

$$\therefore \quad \frac{v}{u} = \frac{v - f}{f}$$

$$\therefore \quad vf = uv - uf$$

$$\therefore \quad vf + uf = uv$$

Dividing across by *uvf*

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

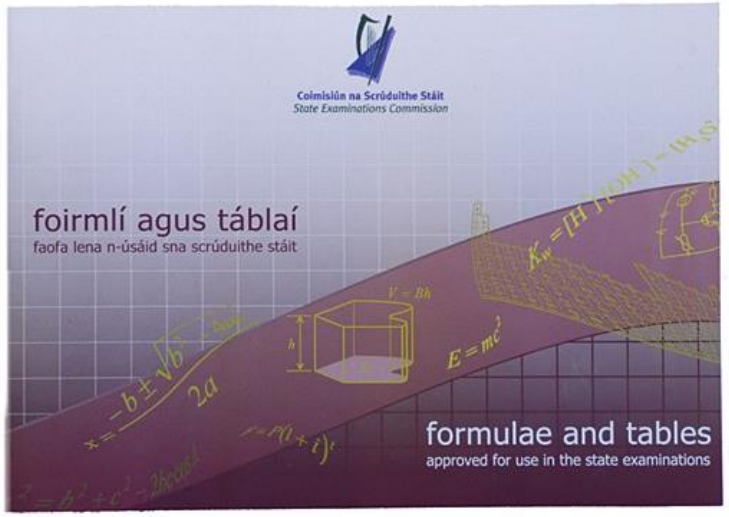
O'Donoghue (1971)

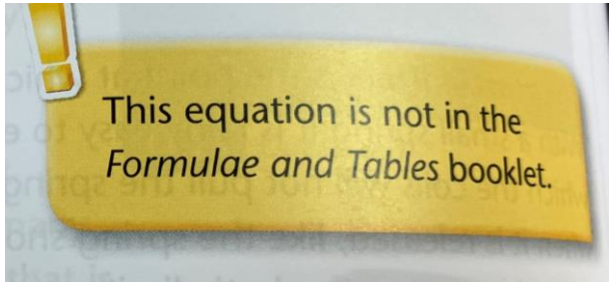
The formula book

Calculators since 1986

Formula book 2010

Shifted the emphasis onto applying formula and away from deriving and proving maths results





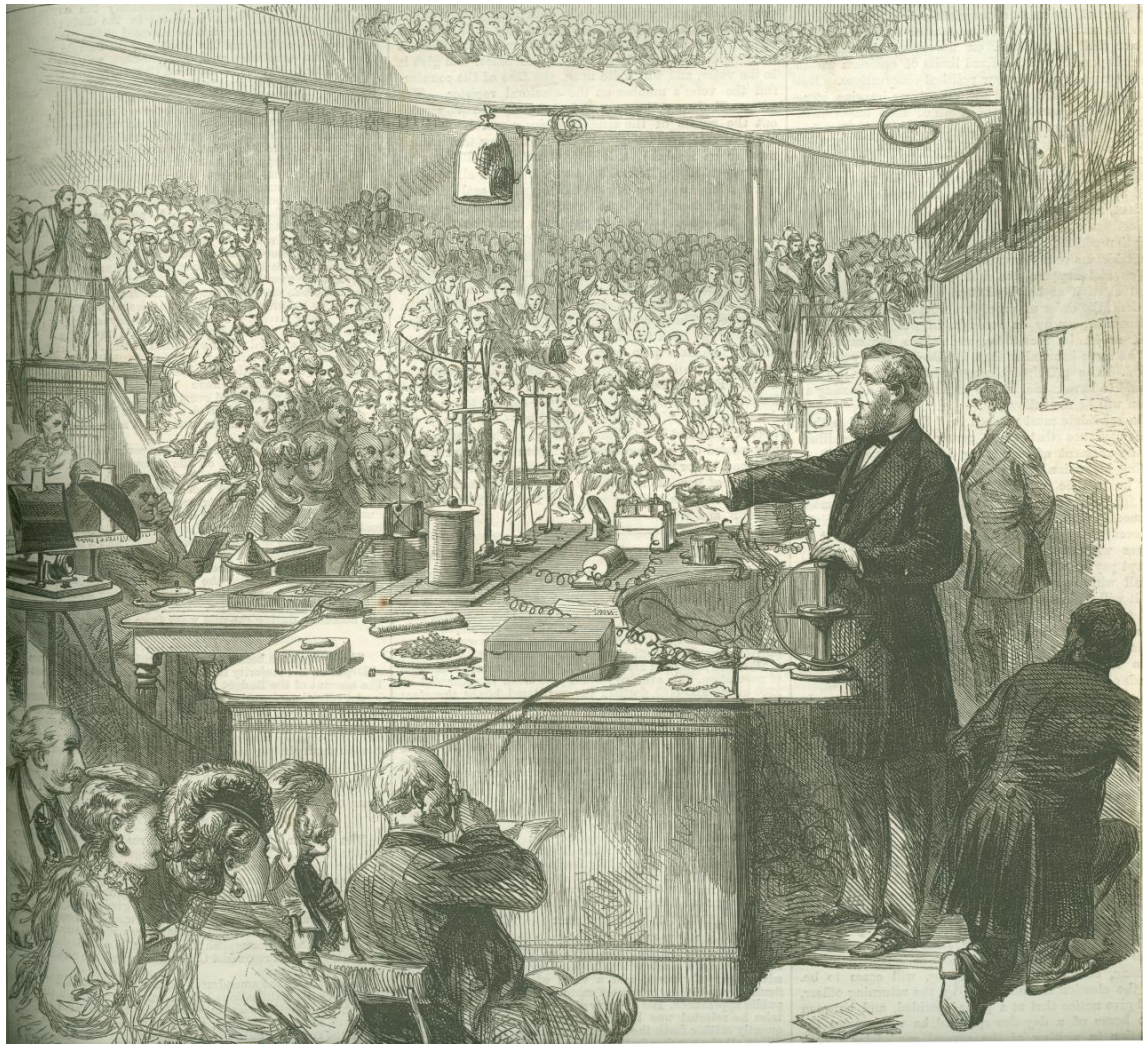
Demonstrations

Tyndall's preferred style for communicating Physics

> The book is intended for use in connexion with a course of lectures, which should include practical demonstrations on the lecture table. I have made no attempt to give the practical details of the experiments described, as these can be learnt only in the laboratory. Every student should endeavour to work through the numerical examples at the ends of the chapters, and should write out answers to some of the examination questions at the end of the book, as only in this way can a clear understanding of the subject be obtained.

Stead (1924)

Convenient when not enough equipment available



Experiment: Focal length of concave mirror

Method 4. Formula method: Another accurate method of measuring the focal length is to apply the formula

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

The mirror is set in a stand and a pin, stuck in a cork or wooden block, is placed between its focus and its centre of curvature. This pin acts as object and forms a real, magnified and inverted image beyond the centre of curvature. A second pin, called a search pin, is moved along the axis of the mirror until the position of no parallax between it and the image of the object pin is found. The search pin now marks the position of the image. The distance from the object pin to the mirror gives the value of u and the distance from the search pin to the mirror gives the value of v. The value of f may then be calculated from the formula. Several sets of values for u and v are found and the value of f calculated in each case. The mean value of f is then calculated.

Instead of using pins, an illuminated cross-wires may be used as object and a screen used to locate the position of the image, although this method is not as accurate as the no parallax method of the pins.

A value for f may also be calculated graphically. Plot the values of $\frac{1}{v}$ against $\frac{1}{u}$ as shown and then draw a straight line through the points. Since

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

O'Donoghue (1971)

2.3 Concave Mirrors

A concave mirror is one in which the reflecting surface is curved inwards — like a cave! Most concave mirrors are spherical, *i.e.* are part of the surface of a sphere.

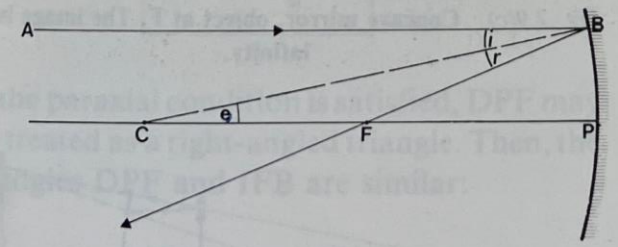
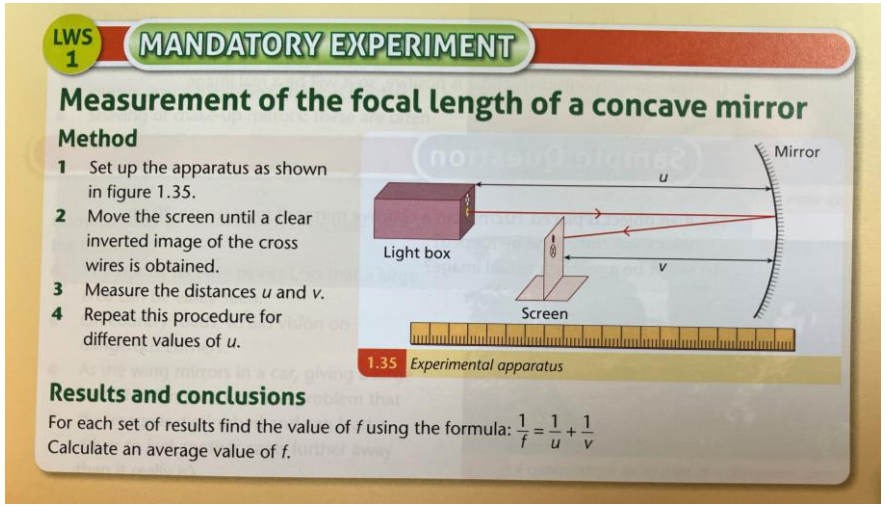


Fig. 2.7 **Reflection at a concave mirror.**

Terms used in connection with concave mirrors are shown in *Fig. 2.7.* P is the **pole** of

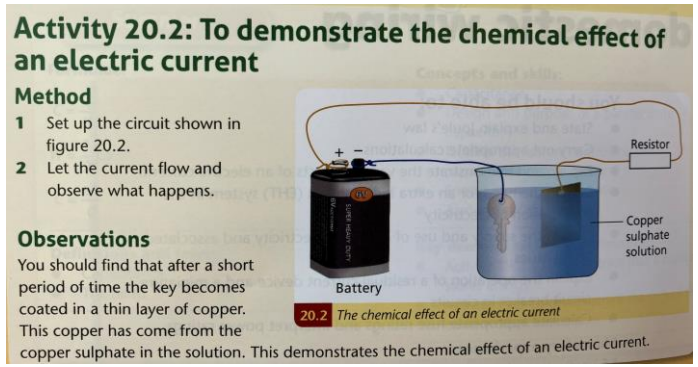
Porter (1984)



Tierney (2014)

Practical Work

1. Recommended demonstrations



Activity 20.2: To demonstrate the chemical effect of an electric current

Method

1. Set up the circuit shown in figure 20.2.
2. Let the current flow and observe what happens.

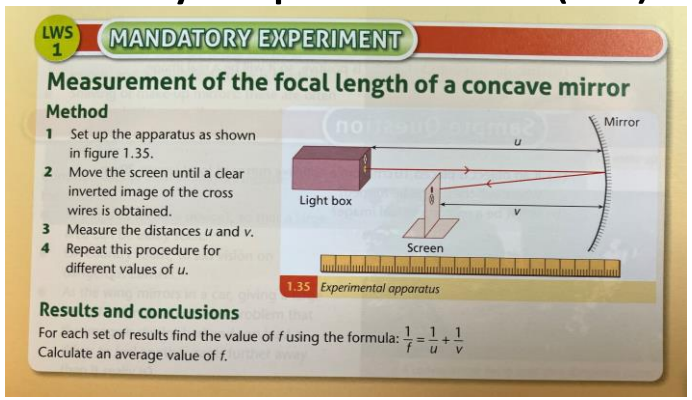
Observations

You should find that after a short period of time the key becomes coated in a thin layer of copper. This copper has come from the copper sulphate in the solution. This demonstrates the chemical effect of an electric current.

20.2 *The chemical effect of an electric current*

Tierney (2014)

2. Mandatory experiments (24)



LWS 1 **MANDATORY EXPERIMENT**

Measurement of the focal length of a concave mirror

Method

1. Set up the apparatus as shown in figure 1.35.
2. Move the screen until a clear inverted image of the cross wires is obtained.
3. Measure the distances *u* and *v*.
4. Repeat this procedure for different values of *u*.

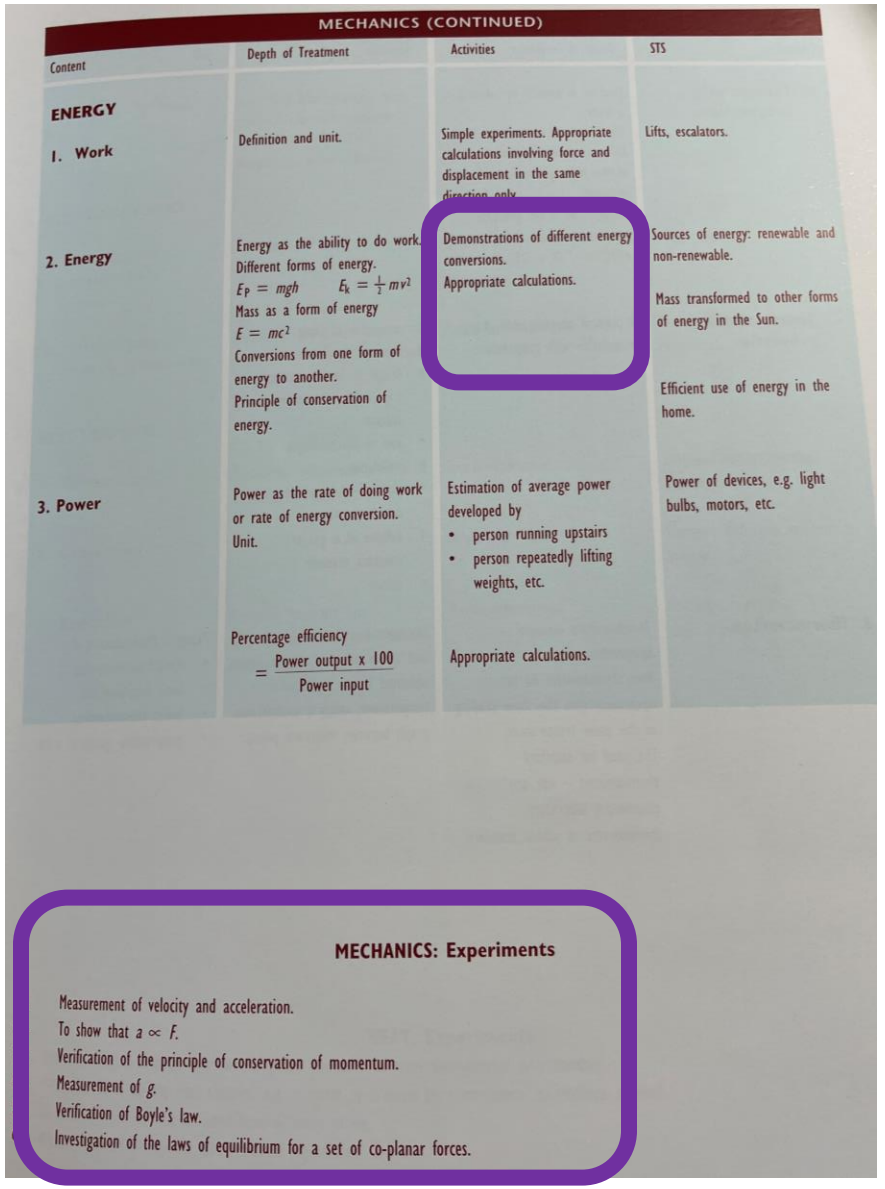
1.35 *Experimental apparatus*

Results and conclusions

For each set of results find the value of *f* using the formula: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Calculate an average value of *f*.

Tierney (2014)



MECHANICS (CONTINUED)

Content	Depth of Treatment	Activities	STS
ENERGY			
1. Work	Definition and unit.	Simple experiments. Appropriate calculations involving force and displacement in the same direction only.	Lifts, escalators.
2. Energy	Energy as the ability to do work. Different forms of energy. $E_P = mgh$ $E_k = \frac{1}{2}mv^2$ Mass as a form of energy $E = mc^2$ Conversions from one form of energy to another. Principle of conservation of energy.	Demonstrations of different energy conversions. Appropriate calculations.	Sources of energy: renewable and non-renewable. Mass transformed to other forms of energy in the Sun. Efficient use of energy in the home.
3. Power	Power as the rate of doing work or rate of energy conversion. Unit.	Estimation of average power developed by • person running upstairs • person repeatedly lifting weights, etc.	Power of devices, e.g. light bulbs, motors, etc.
	Percentage efficiency $= \frac{\text{Power output} \times 100}{\text{Power input}}$	Appropriate calculations.	

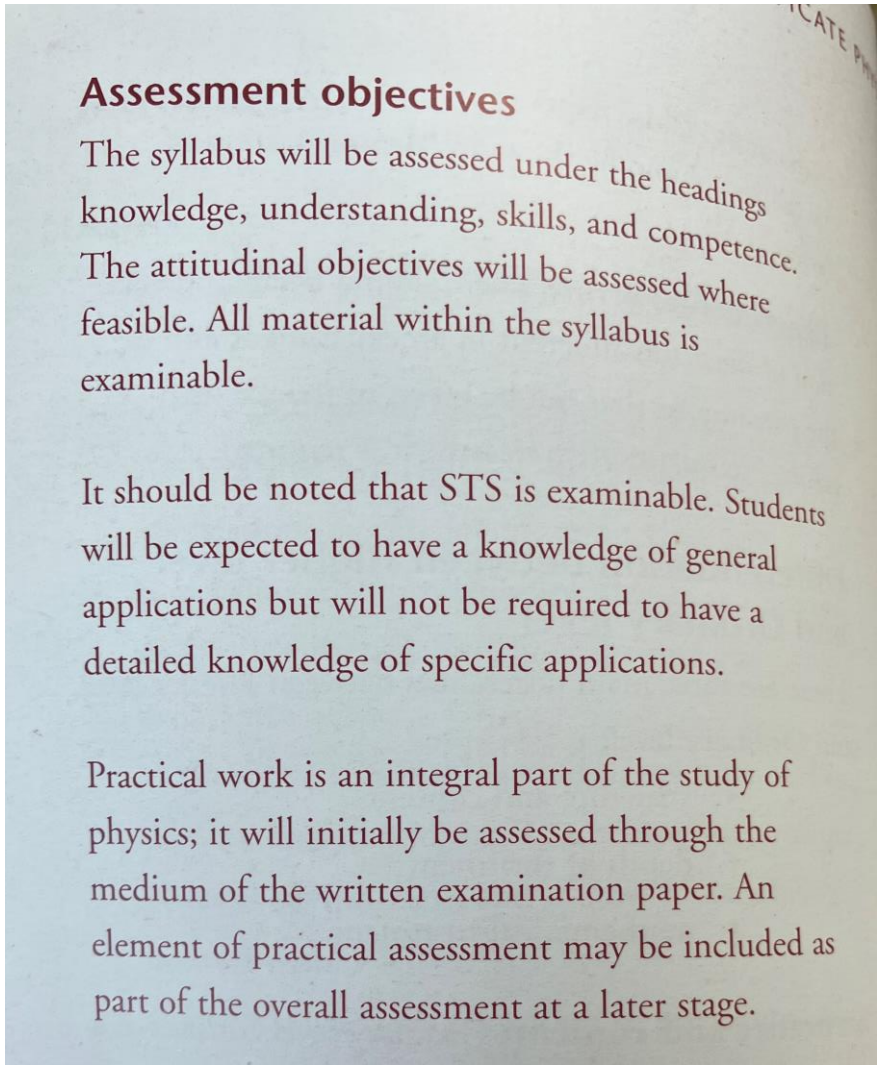
MECHANICS: Experiments

Measurement of velocity and acceleration.
To show that $a \propto F$.
Verification of the principle of conservation of momentum.
Measurement of *g*.
Verification of Boyle's law.
Investigation of the laws of equilibrium for a set of co-planar forces.

Syllabus (2000)

Practical Work

- Students have never been assessed with equipment in their hands
- Experiments always encouraged, and asked about in exam papers
- Moving to situation of textbook being a student reference rather than a teaching tool



Assessment objectives

The syllabus will be assessed under the headings knowledge, understanding, skills, and competence. The attitudinal objectives will be assessed where feasible. All material within the syllabus is examinable.

It should be noted that STS is examinable. Students will be expected to have a knowledge of general applications but will not be required to have a detailed knowledge of specific applications.

Practical work is an integral part of the study of physics; it will initially be assessed through the medium of the written examination paper. An element of practical assessment may be included as part of the overall assessment at a later stage.

Syllabus (2000)

Representation of Women

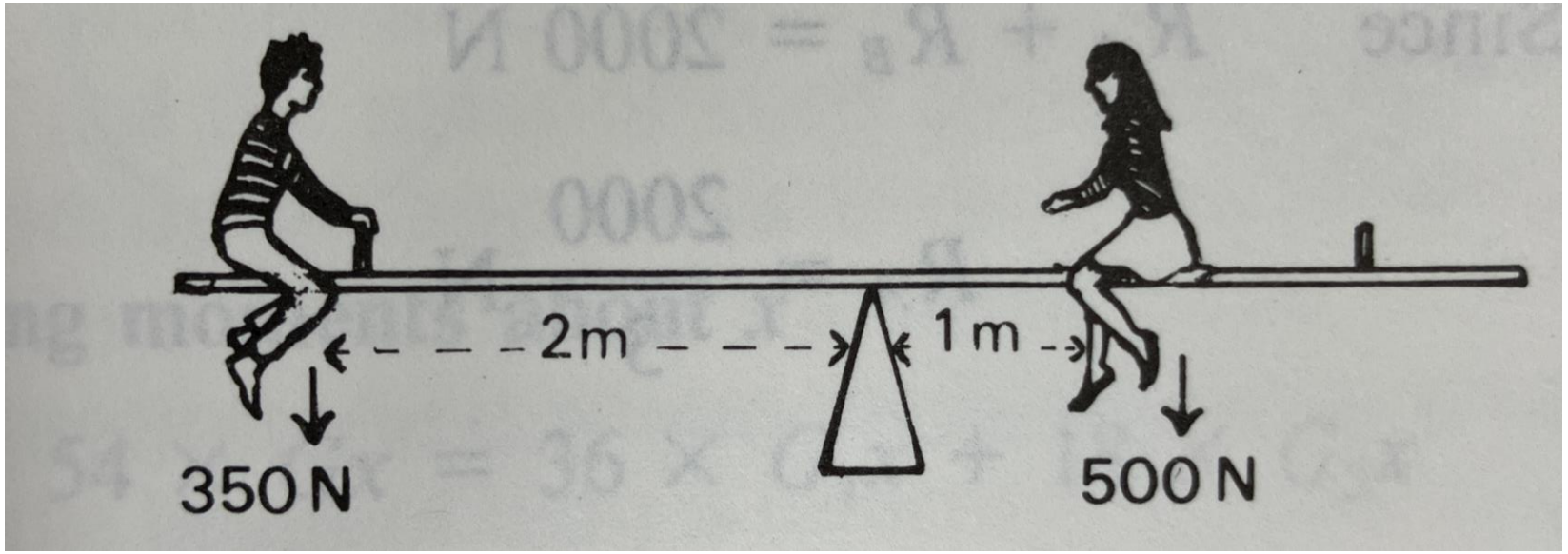
“It may be hoped that this volume may be the means of extending instruction in the first notions of Physics into Ladies’ schools. Female teachers in general will find even the Hand Book easily intelligible, and by it will be enabled to use the present volume for the instruction of their pupils.”

Lardner (1865)

Representation of Women

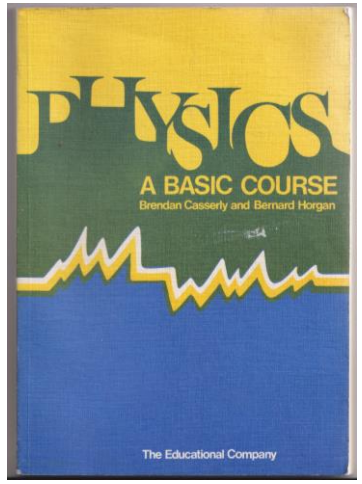
- Authors of all textbooks studied are male
- A recent study (Karen Pillion) of four Irish textbooks published since 2000 revealed that females are drastically under-represented, with women only accounting from between 13% and 28% of characters shown in image throughout.
- Furthermore, only two female scientists are discussed in comparison with references made to 91 male scientists.

Representation of Women



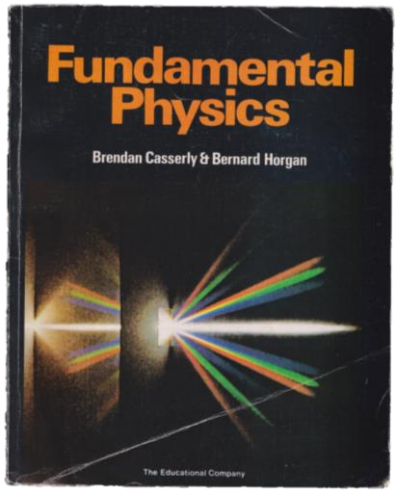
Casserly and Horgan (1984)

Trio of textbooks by Casserly and Horgan



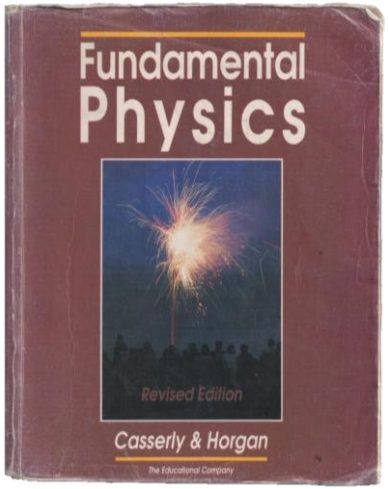
1981

- Almost a revision guide
- Very economical



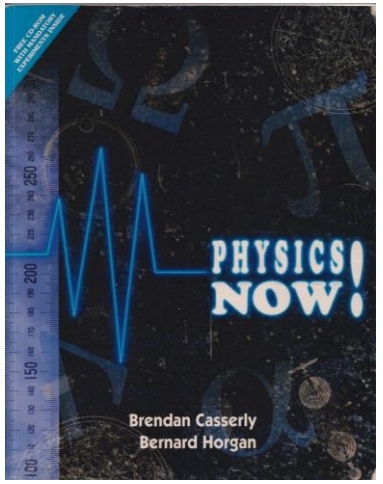
1984

- Had clarity and style. No colour or photos despite being possible



1990

- Reformatting of 1984 book with updates



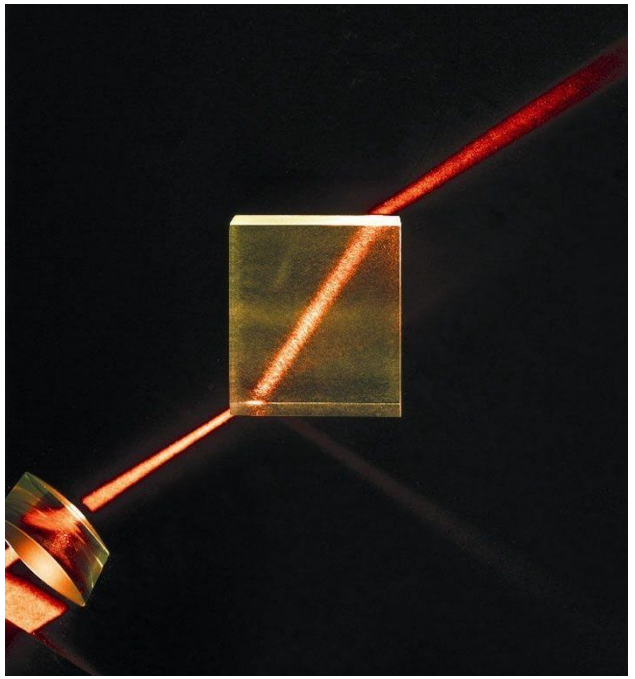
2000

- Published for new syllabus

Case Studies

Special attention on:

The Electroscope

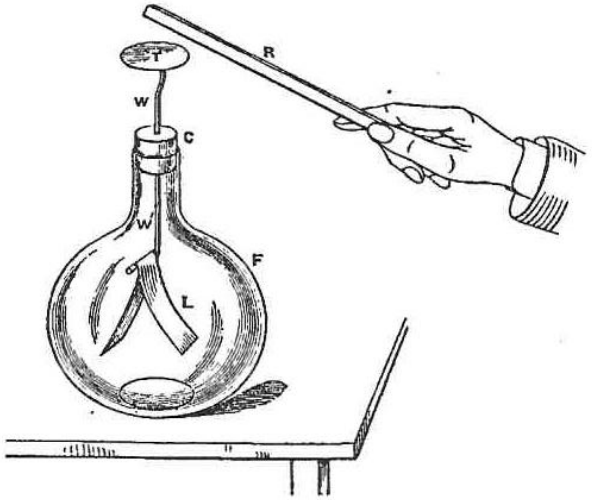


Refraction of Light

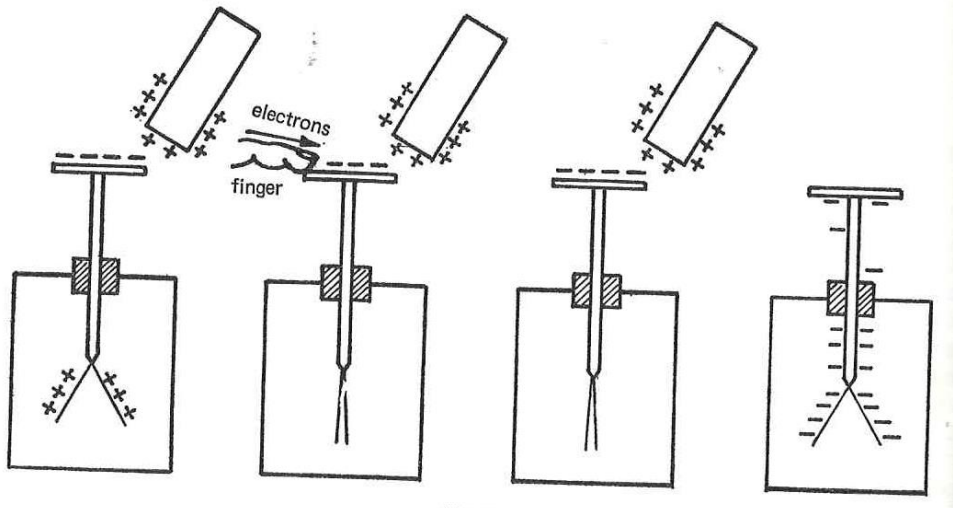
findings would be firmly rooted in how Physics has been represented in textbooks rather than general textbook publishing trends

The Electroscope

- Electrostatics was a novelty for the Victorians, electricity was still in its infancy. Tyndall's diagrams didn't feature + and -
- More recent textbooks have the same diagrams but expect students to be able to explain why + and – are where they are



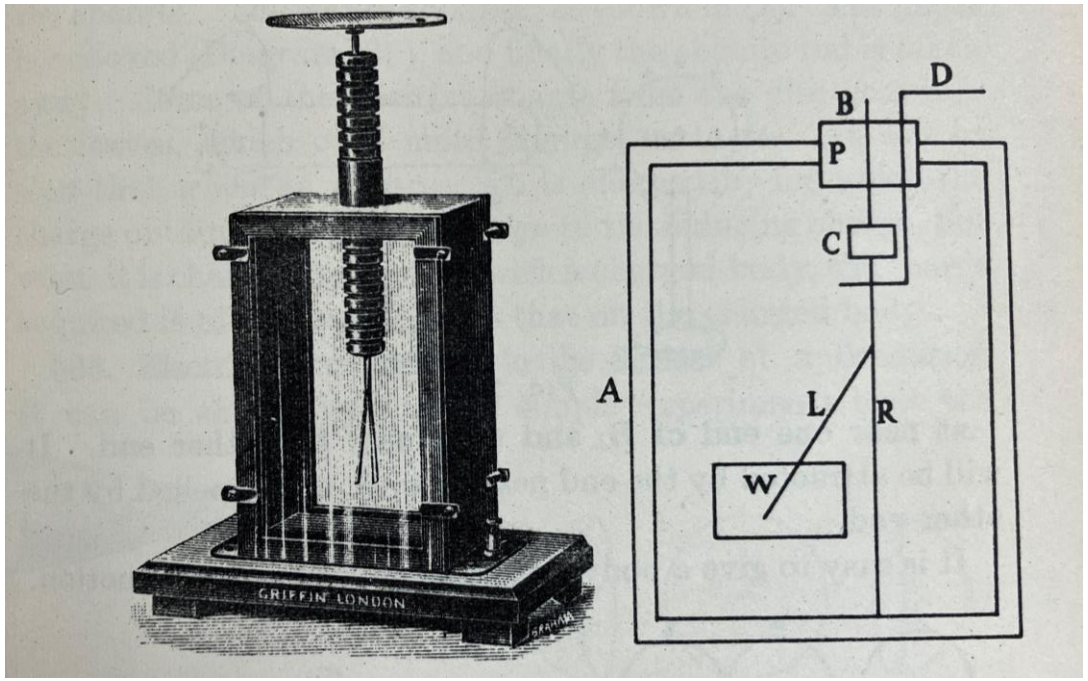
Tyndall (1871)



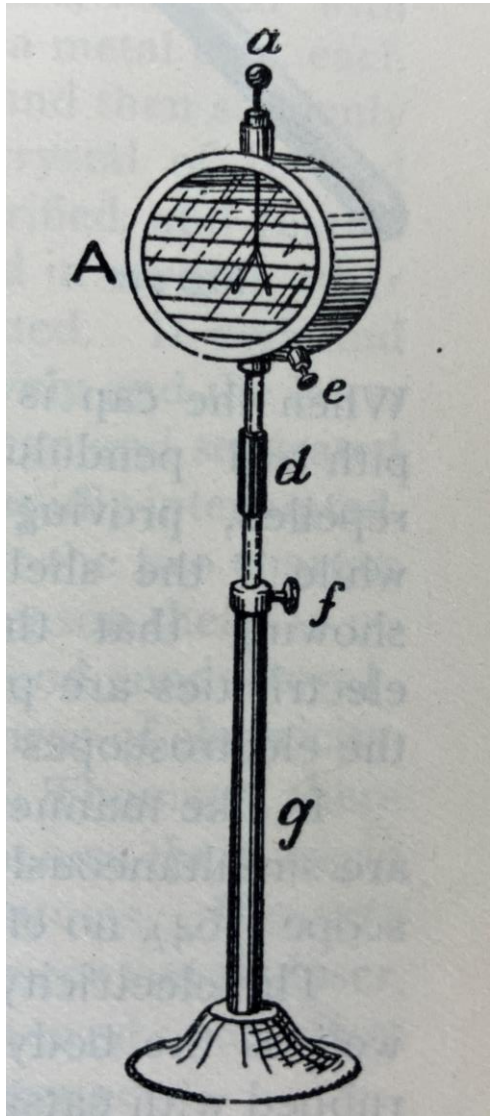
O'Donoghue (1971)

The Electroscope

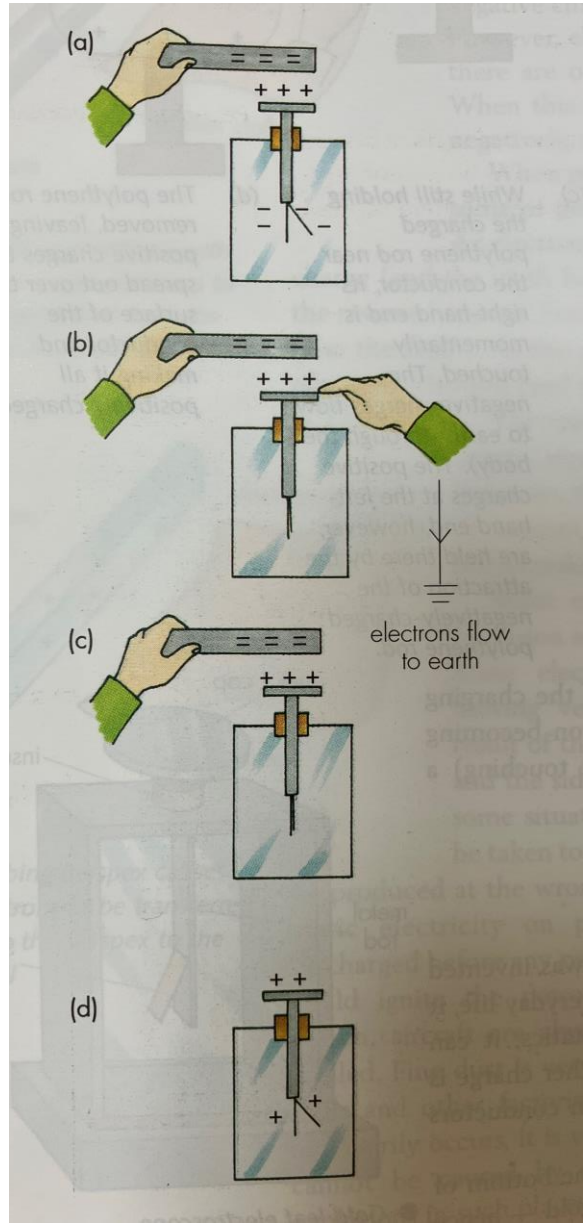
Present in all textbooks, represented very differently



Stead (1924)



Ganot (1906)



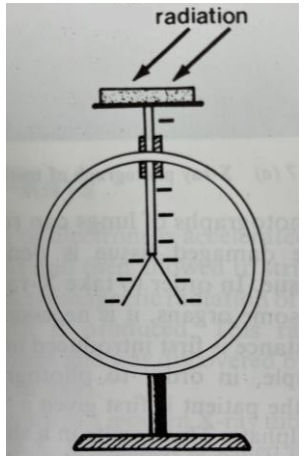
Henly (2000)

The Electroscope

- A lab instrument for the most part

- Except for brief application in time of Marie Curie and the discovery of radiation – photographic film very expensive

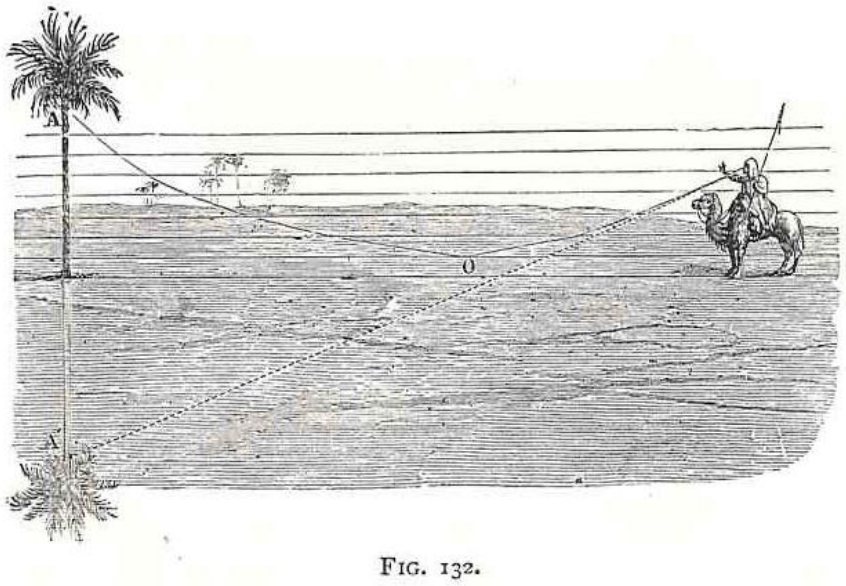
- Modern times – value is in preparing students for explaining electricity in terms of moving charges



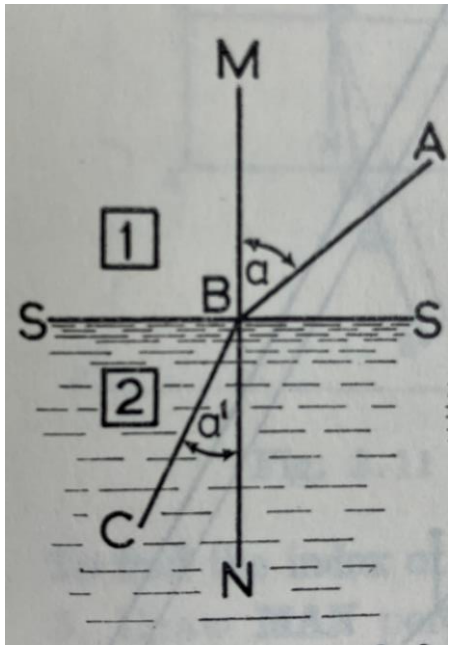
Porter (1984)

Refraction of Light

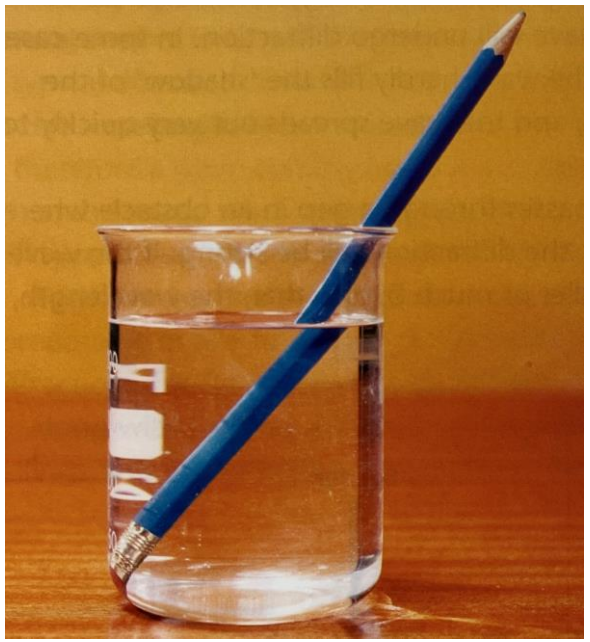
Remarkable stability over 160 years in examples and images



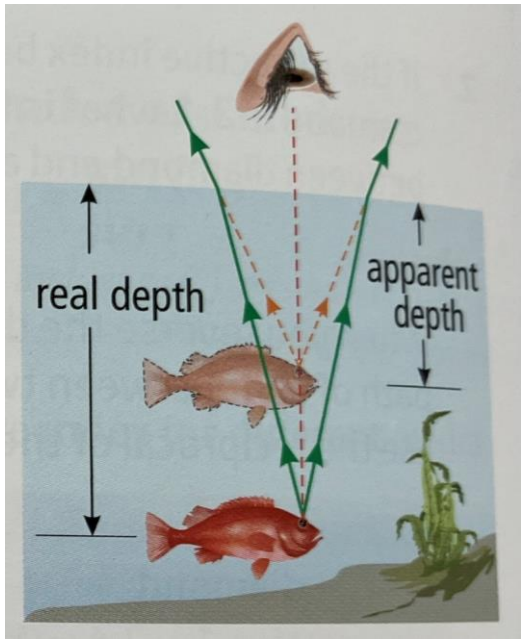
Mirage (Lardner, 1865)



O'Brien (1962)



Bent stick
(Tierney, 2014)



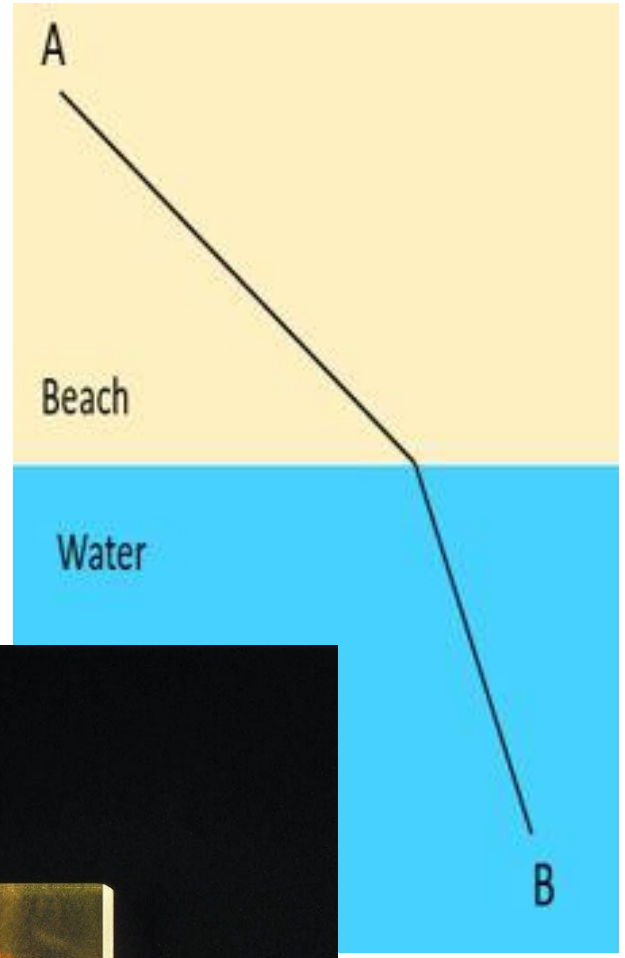
Apparent Depth
(Carolan, 2013)

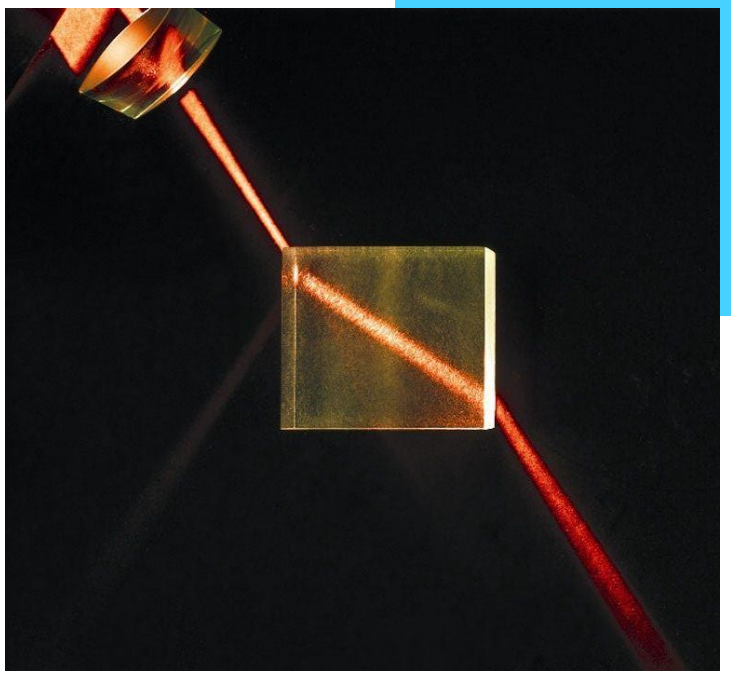
Refraction of Light

- The reason the light changes direction is due to the change in speed of the light through denser media

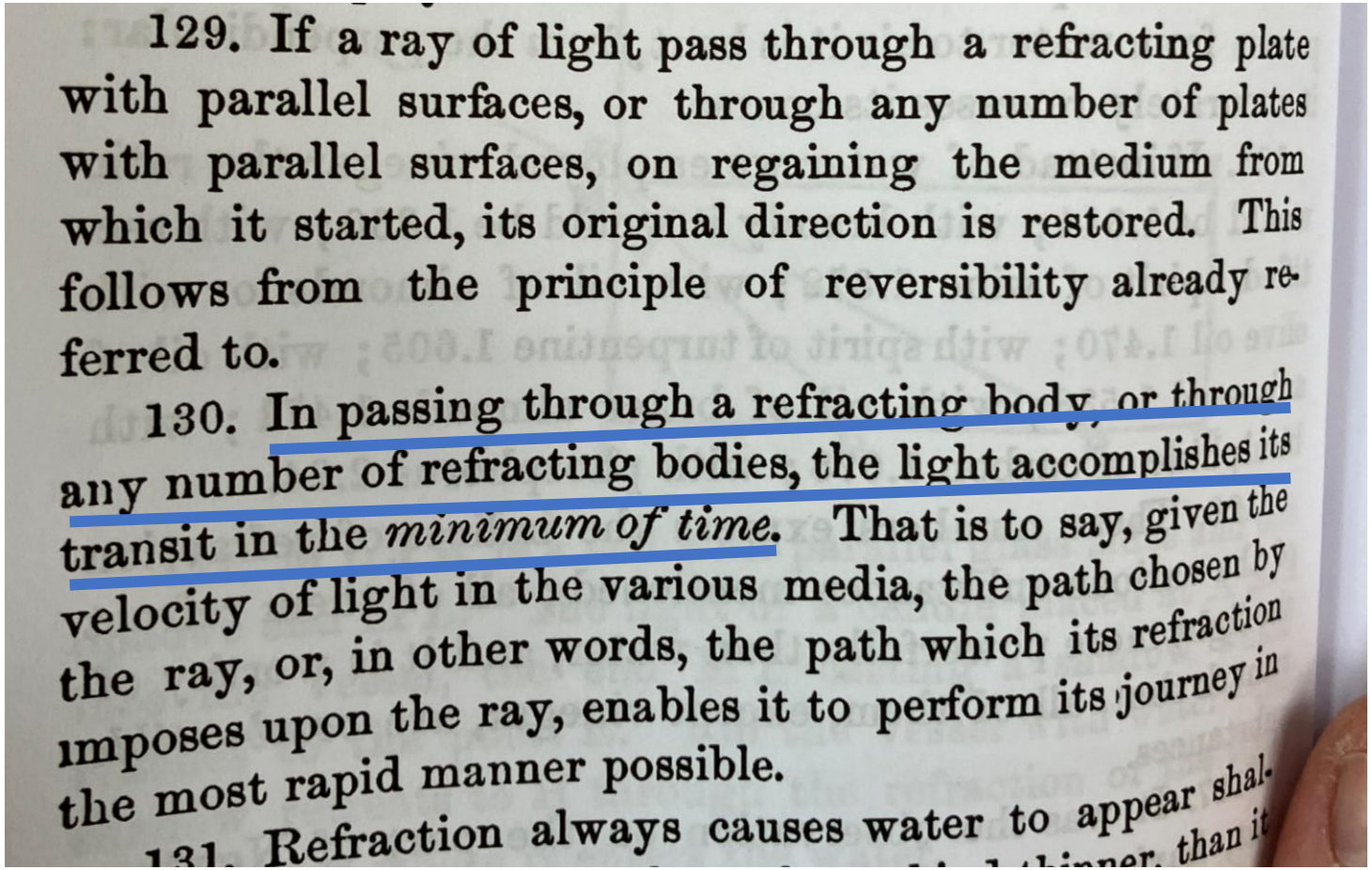
- Little emphasis on this in the earliest times, reached a peak in the 1960s 70s and 80s and less emphasized since

- The underlying elegant truth that light takes the FASTEST route through a prism – is lost





Refraction of Light

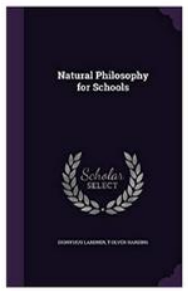


129. If a ray of light pass through a refracting plate with parallel surfaces, or through any number of plates with parallel surfaces, on regaining the medium from which it started, its original direction is restored. This follows from the principle of reversibility already referred to.

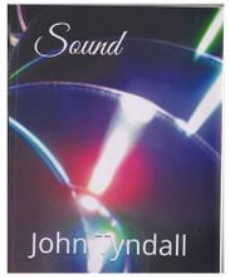
130. In passing through a refracting body, or through any number of refracting bodies, the light accomplishes its transit in the *minimum of time*. That is to say, given the velocity of light in the various media, the path chosen by the ray, or, in other words, the path which its refraction imposes upon the ray, enables it to perform its journey in the most rapid manner possible.

131. Refraction always causes water to appear shal-

Lardner (1865)



1865



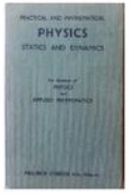
1875

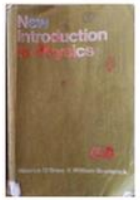
4 decades

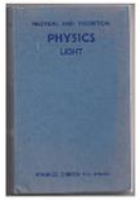
1906

LC Introduced

1924

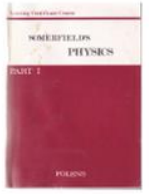


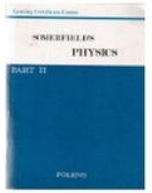




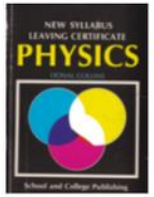
Revised Course

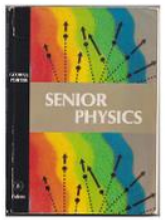
1962

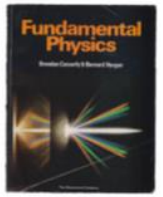




1972

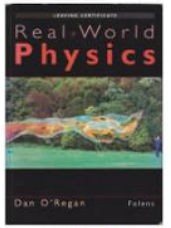


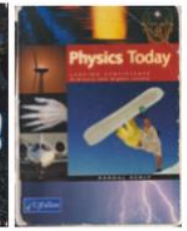




1984

Revised Course

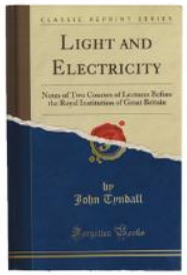




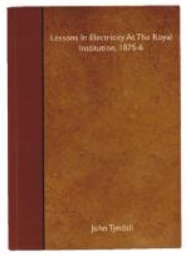
2000

Revised Course

1871

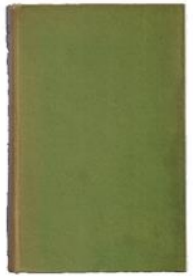


1876



1888

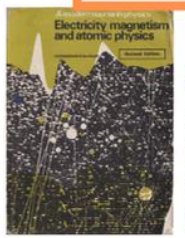
1924

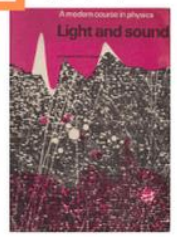


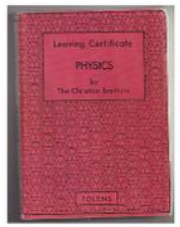
4 decades
(8 editions)

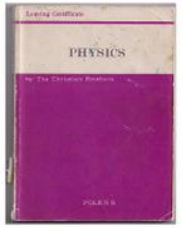
Revised Course

1971

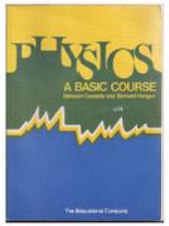




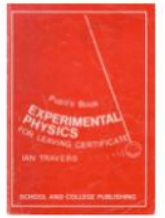




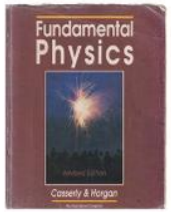
1981



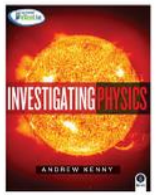
1987



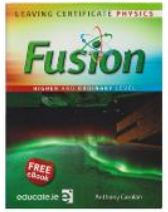
1990



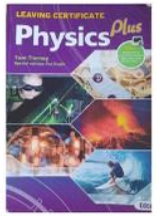
2010



2013



2014



Any Questions?

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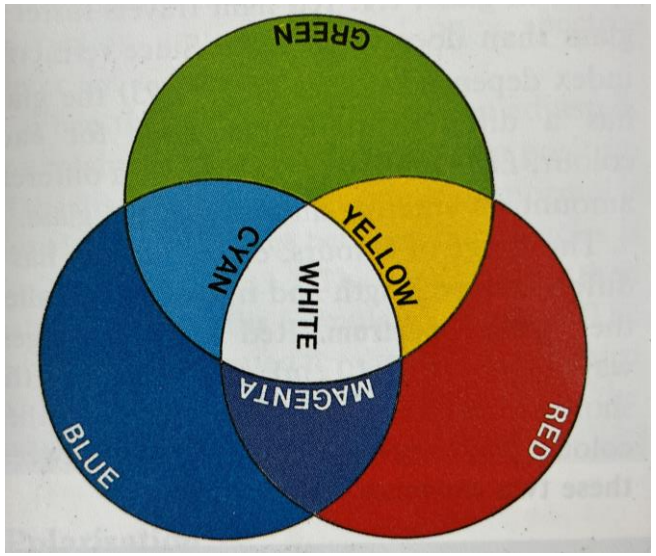
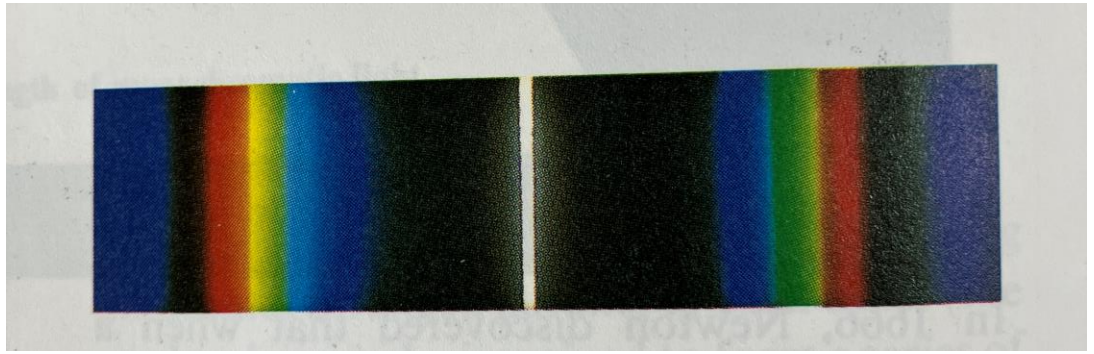
Extra on Diagrams

Advances in colour printing

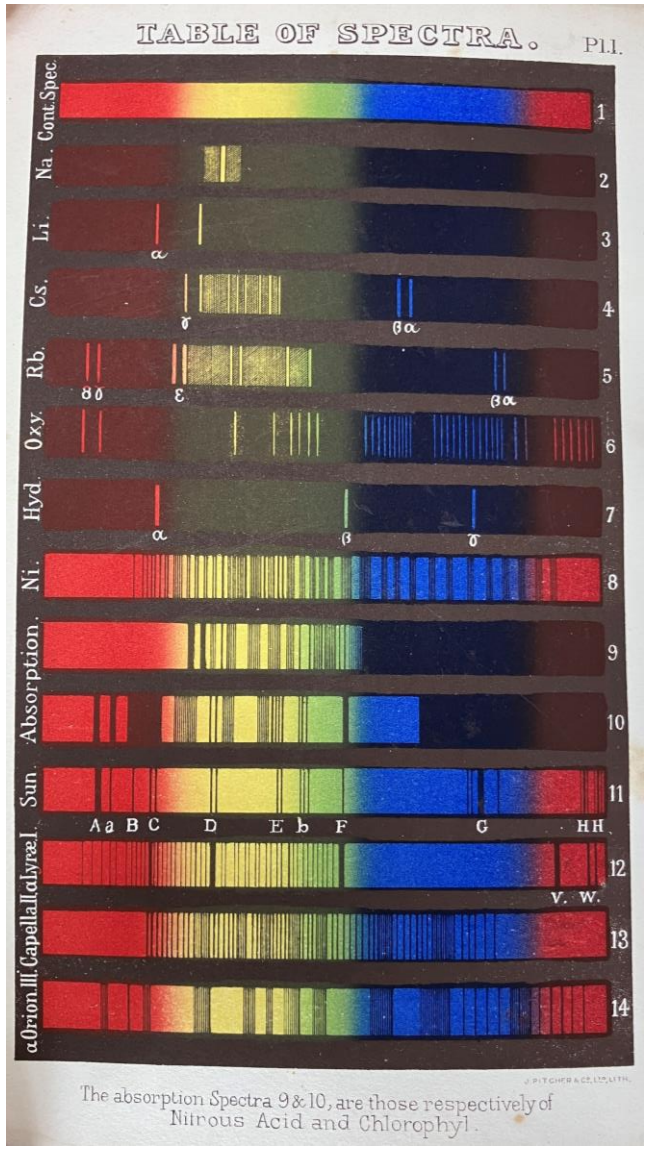


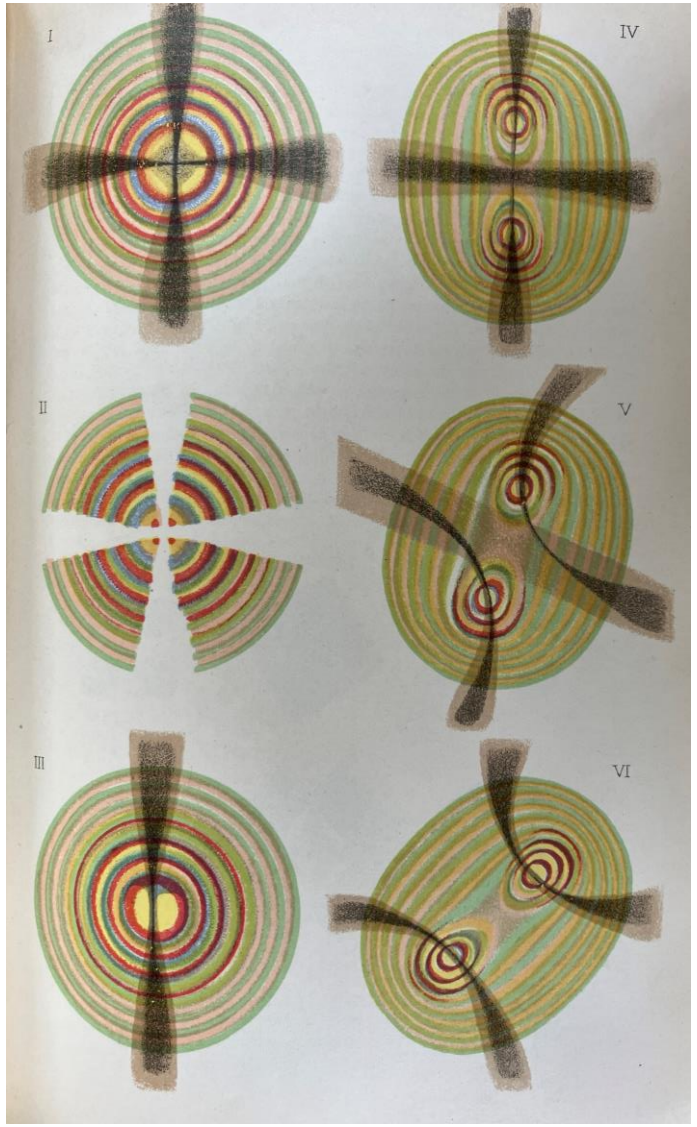


Porter (1984)

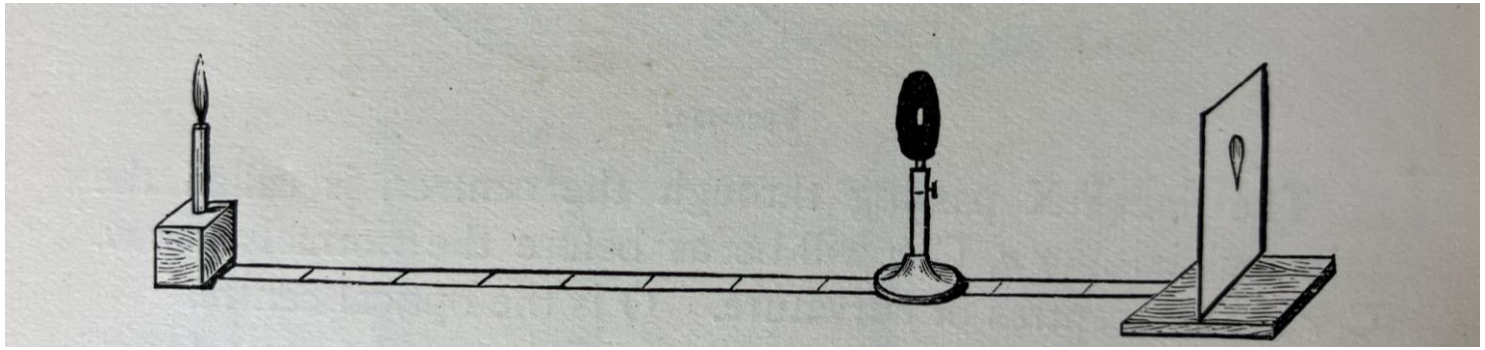
Extra on Diagrams

Advances in colour printing

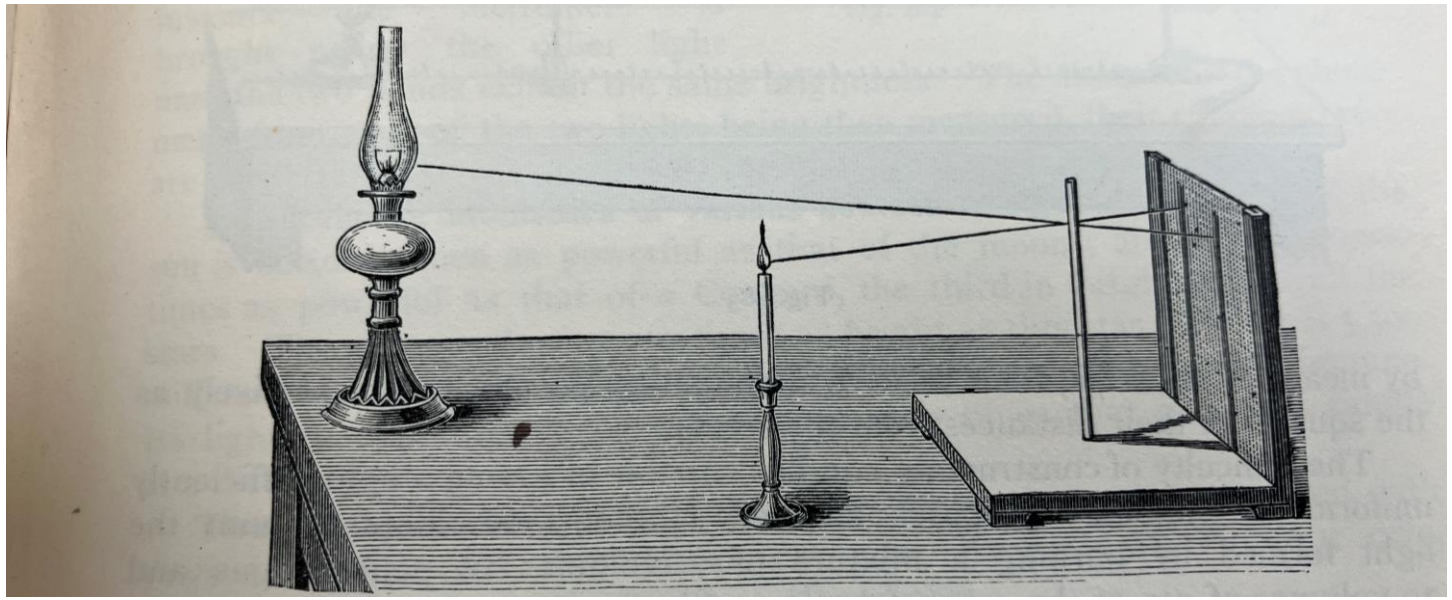




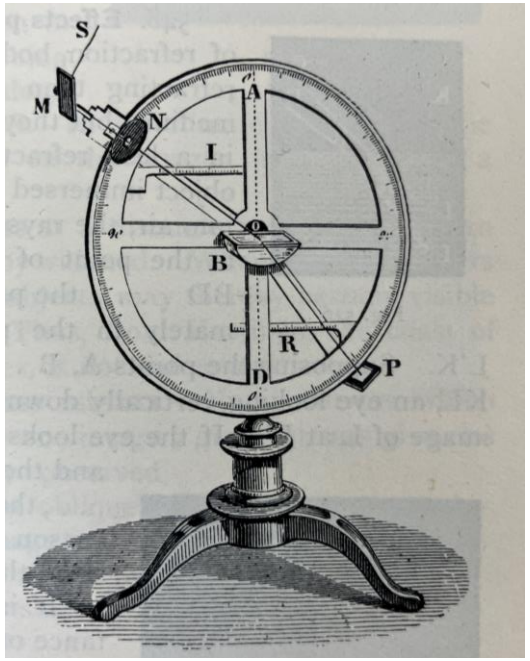
Ganot (1906)



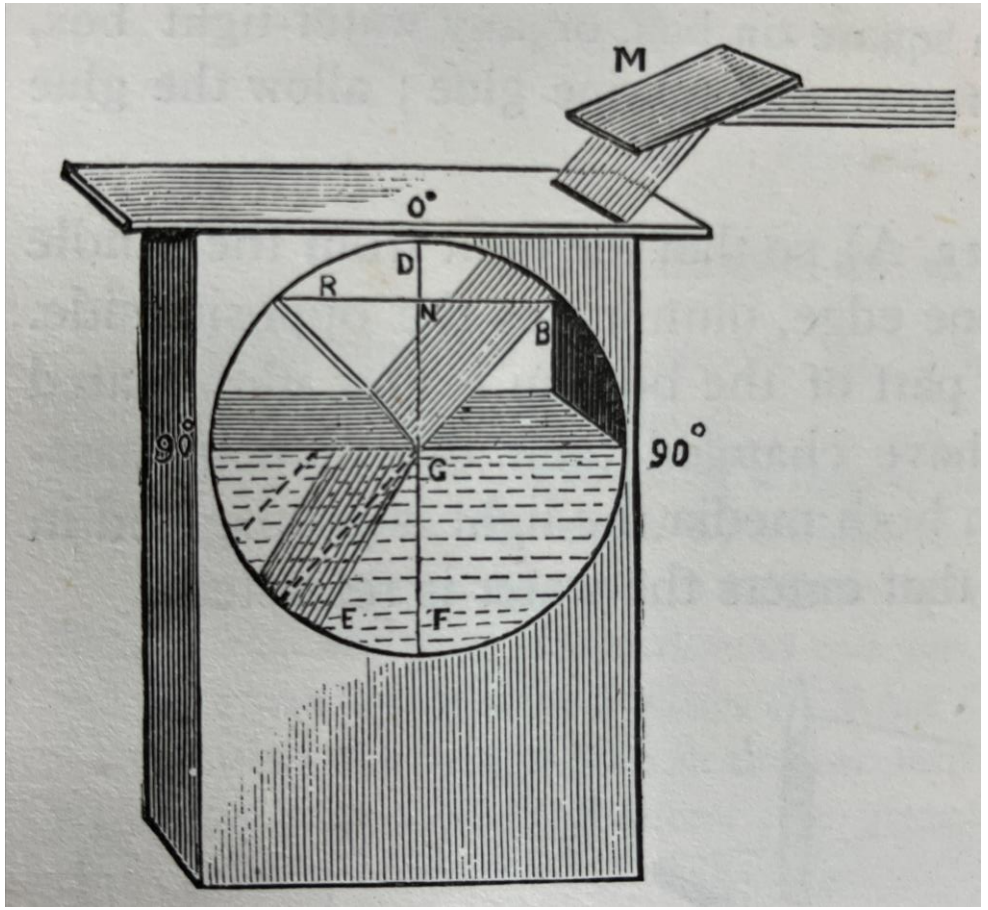
Wright (1888)



Ganot (1906)



Ganot (1906)



Wright (1888)