Hydrostatics and Mechanics

A. E. E. McKenzie

HYDROSTATICS AND MECHANICS
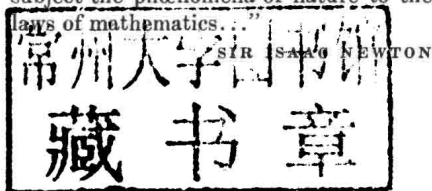
by

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"...the moderns...have endeavoured to
subject the phœnomena of nature to the
laws of mathematics..."

SIR ISAAC NEWTON

CAMBRIDGE

AT THE UNIVERSITY PRESS

1934

HYDROSTATICS AND MECHANICS

PREFACE

This book is the first of three volumes covering the sections into which Physics is usually divided—Mechanics and Hydrostatics; Heat, Light and Sound; and Electricity and Magnetism. The aim is to provide a complete elementary course of Physics from the beginning up to School Certificate and 1st M.B. Standard.

Mechanics is often considered by boys as one of the dullest parts of Physics, despite the fact that it is the basis of many of the greatest engineering achievements. A considerable number of illustrations have therefore been provided and references have been made to the applications of Mechanics, partly to make real the scientific theory and partly to stimulate interest. For "the mind of a child is not a vessel to be filled, but a torch to be kindled".

One of the essentials in science teaching is an adequate supply of suitable problems, which test a boy's mastery of the principles and call for the exercise of thought as well as of memory. Care has been taken in the collection of problems at the end of each chapter and selected School Certificate examples have also been provided.

I am indebted to Mr D. G. A. Dyson for reading the proofs and making many valuable suggestions, for drawing the line diagrams, and also for the ingenuity and time he has expended in perfecting the photograph of the falling and bouncing ball; to my colleague, Mr R. E. Williams, for reading the proofs and generously placing his experience at my disposal; and to Mr W. D. M. Paton and Mr G. S. Dawes for checking the answers to the examples.

Many of the illustrations have been provided by engineering firms and publishers, acknowledgement to whom has been made

under the illustrations in question. Mr F. J. Spencer of Stratford-on-Avon kindly allowed me to reproduce the photograph of the pile driver.

Finally I must express my thanks to the following examining bodies who have given me permission to reproduce School Certificate Questions: the Oxford and Cambridge Joint Board, the Northern Universities Joint Matriculation Board, and the Cambridge Local Examinations Syndicate.

A. E. E. M.

Repton
April 1934

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SECTION I. MEASUREMENT AND HYDROSTATICS

Chapter I

MEASUREMENT AND UNITS

Introduction. The scientific method.

The aim of this book is to give a simple knowledge of what is meant by Science, and to help those who read it to become in some degree scientists.

It deals with a special branch, known as Physics, upon which the rest of science is based. Bridges, railway engines, motor cars, aeroplanes and wireless sets all depend for their construction and working on the principles of Physics.

The scientific method is to collect as many facts as possible and endeavour to generalise them into a law, or explain them by means of a theory. Usually these facts can only be obtained by means of experiments; indeed, science has been defined as the pursuit of truth by the experimental method.

The detective uses the scientific method in his investigation of crime. He collects all the clues he can, and then invents a theory to fit them. Often his first theory proves incorrect. New facts come to light, showing, perhaps, that his suspicions have fallen upon the wrong person. He then has to invent a new theory. In the same way scientific theories are changed or modified with the discovery of fresh facts.

Many of the greatest discoveries of science have only been possible as a result of very accurate measurements, and the first part of the training of a scientist is the learning of this technique.

Measurement of length.

To measure accurately the length of an object is not so easy as it looks. It is true that to find the approximate length of a bar, all that needs to be done is to lay a ruler alongside, and read the position of both ends. But even in this approximate reading there is a source of error which is liable to give wrong results to those who are not carefully on their guard against it. If the ruler is lying on a table or bench it is essential that the eye should

be directly above the end of the bar when its position is being read. If the head is moved it will be found that the reading changes slightly, and this is known as the **error due to parallax**. Fig. 1 shows this. If the ruler is vertical it is likewise necessary
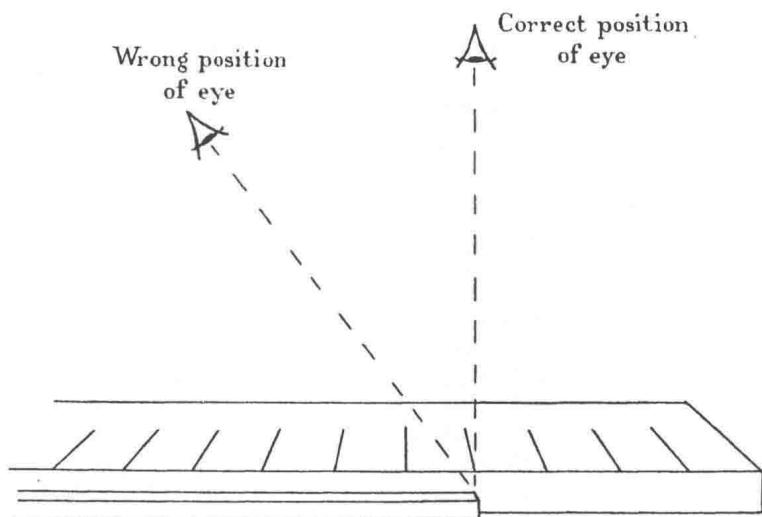
Fig. 1. Error due to parallax.

to have the eye at the same horizontal level as the reading taken, even though this may necessitate climbing on a stool, or kneeling on the ground.

The vernier.

When measuring with a ruler one can attempt to estimate by eye to a tenth of a millimetre, but even after much practice this is difficult and uncertain. By fitting a small sliding scale to the ruler it is possible to measure to this degree of accuracy quite easily. Such an arrangement is called a vernier, after its inventor.

The sliding scale is of length 9 mm., but is divided into ten divisions, so that each division is of length 0·9 mm.

To use the instrument the sliding scale is pushed right up against the object to be measured, as in **Fig. 2**. The length of the object in the figure is seen to be 3 and a fraction. The fraction is

found by looking along the sliding scale and noting which mark is most nearly opposite a mark on the main scale. In this case it is 7, and we take the length of the object as 3·7.

It is a good plan to make a vernier for yourself from two pieces of cardboard, with wide divisions that can easily be marked off accurately. The divisions on the main scale should be 1 cm. long and those on the sliding scale 9 mm. The result will look very
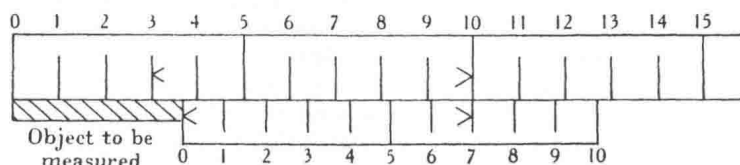
Fig. 2. Vernier.

like Fig. 2. This vernier will read correct to the nearest millimetre and its accuracy can be tested by measuring a body first with the vernier and then with an ordinary ruler.

Fig. 3 shows steel vernier calipers being used to find the diameter of a penny (calipers consist of jaws with which to grip an
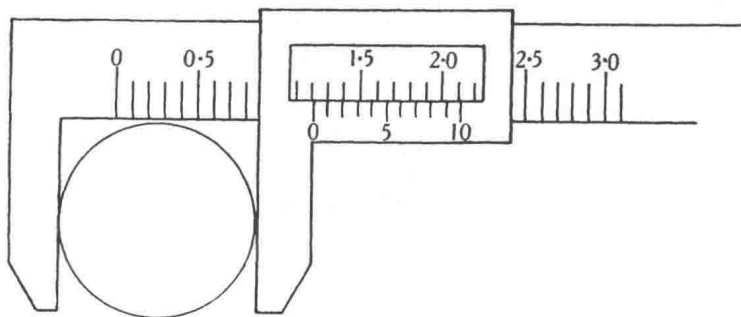
Fig. 3. Vernier calipers being used to find the diameter of a penny (in inches).

object). It is graduated in inches (drawn to a reduced scale). What is the diameter? Read first the position on the main scale of the zero mark of the vernier scale; this will give you the length to the first decimal place. Now look for the mark on the sliding scale which will give you the second decimal place. The answer

is given in a note at the end of the chapter. Do not refer to it until you have taken your own reading.

Why the vernier works.

Look at Fig. 2. Why does it follow that the fraction to be measured is 0·7 simply because the 7 mark on the vernier is opposite a mark on the main scale?

Two pairs of arrowheads have been marked in the figure. The distance between the upper pair is 7 and that between the lower pair is $7 \times 0·9 = 6·3$. The difference between these two distances, which is the required fraction, is thus $7 - 6·3 = 0·7$.

The object extends slightly beyond the 3 mark on the main scale, and the sliding scale starts with this extension as a handicap. It gained 0·1 in every division. Since it requires 7 divisions to catch up, its handicap is $7 \times 0·1 = 0·7$. This explains why each division on the sliding scale is made 0·1 shorter than the divisions on the main scale.

Let us consider one other way of looking at this problem. Suppose the sliding scale pushed right home so that the 0 marks on the two scales are opposite. Now move the sliding scale so that the 1 marks are opposite. It has been moved 0·1. When the 2 marks are opposite it has been moved 0·2, and when the 7 marks are opposite it has been moved 0·7, so that the gap between the ends of the two scales is 0·7.

The micrometer screw gauge.

If we wish to find the diameter of a hair or the thickness of paper, even a vernier is useless. We make use of a micrometer screw gauge (see Fig. 4), which can measure to one-hundredth of a millimetre.

Before reading the following description you should get hold of one of these instruments and handle it.

It consists essentially of a very accurate screw with a pitch of, say, ½ mm. The pitch is the distance between the mid-points of consecutive threads, measured parallel to the axis. When the screw is turned through one complete revolution it moves forward or backward a distance equal to the pitch. You can imagine, as a large scale model, a spiral iron staircase which you are descending. When you have gone once round the pillar carrying the staircase, you are standing immediately below the point at

which you started, and the vertical distance you have descended is the pitch of the staircase.

Now the head of the micrometer screw is divided into 50 equal divisions, so that each division corresponds to one-fiftieth of a turn, or a forward or backward movement of $\frac{1}{100}$ mm.

When using the instrument the first thing to do is to find the pitch of the screw. Instead of a pitch of $\frac{1}{2}$ mm. it may have a pitch of 1 mm., in which case the head is probably divided into 100 divisions. To find the pitch, turn the screw through four complete turns, and measure with a ruler how far it has moved, whether 2 mm. or 4 mm.
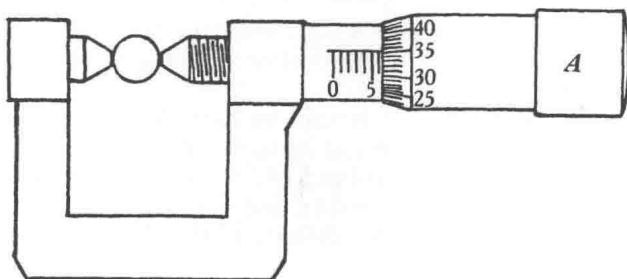

Fig. 4. Micrometer screw gauge.

The "zero error" has now to be determined. Screw the instrument right home, but not too tightly, or you will damage the thread. Usually there is a special cap (A), which, at a certain pressure, turns without moving the screw, and thus prevents damage.

The 0 division on the head of the screw may not be exactly opposite the fixed mark on the frame. This is usually due to a certain amount of play, known as backlash, which has developed through misuse, between the screw and its holder. Note which division is opposite the fixed mark, and determine how many divisions have to be added or subtracted to readings. This is known as the zero correction.

To find the thickness of a piece of cardboard, place it between the jaws of the gauge and screw up. Suppose the gauge has a pitch of $\frac{1}{2}$ mm. Suppose also the reading is 23 divisions, and, in addition, the screw has been turned through one complete revo-

lution. The thickness of the cardboard is 73 divisions, or $\frac{73}{100}$ mm., or 0·73 mm. If the zero correction had been +1 division, the true thickness would have been 0·74 mm.

$$
\begin{array}{lll}
\text{50 divisions} & \text{(one complete turn)} \\
23 \quad \text{,,} & \text{(scale reading)} \\
\underline{1} \quad \text{,,} & \text{(zero correction)} \\
\end{array}
$$

Thickness of cardboard $= \overline{74}$,,
Each division $= \frac{1}{50}$ pitch $= \frac{1}{50} \times \frac{1}{2}$ mm.
Thickness of cardboard $= 74 \times \frac{1}{100}$ mm.
$\qquad\qquad\qquad\qquad = 0\cdot74$ mm.

Units and standards of length and weight.

Rulers and tape-measures are made in factories, and are copies of standard rulers. But where did the standard rulers come from?

The first standard yard is said to have been the length of Henry I's arm, and the foot, as its name implies, was originally the length of an average human foot. Such vague standards are of no use to an instrument maker, and the first yardstick had to be made by Parliament, and defined as the **British Standard Yard.**

When the Houses of Parliament were burnt down in 1834, the old yardstick was damaged and our modern standard dates from 1844. It is the distance between two marks on a bronze bar at a definite temperature (62° F.). It is now in the custody of the Board of Trade, and exact copies of it are kept in such places as the Houses of Parliament, the headquarters of the Royal Society, the Royal Mint and the Greenwich Observatory.

Other units of length are derived from the yard as follows:

$$
\begin{array}{ll}
\text{12 inches} = 1 \text{ foot.} \\
\text{3 feet} \quad = 1 \text{ yard.} \\
\text{1760 yards} = 1 \text{ mile.}
\end{array}
$$

The ratios 12, 3 and 1760 are hardly what one would have chosen when inventing the ideal units of length. Chains, rods, poles, perches and the like, while they may have venerable historical traditions, put a further unnecessary tax on one's memory and arithmetic.

There is a much simpler system, the Metric System, which was invented in 1799, just after the French Revolution. The standard