CHAPTER I

THE WEIGHTS AND DENSITIES OF BUILDING MATERIALS

The Properties of Matter. Before proceeding to discuss the weights and densities of building materials, it will be convenient for us to make here a very brief reference to the more important properties of matter, leaving to the later stages the discussion, in such detail as may be necessary, of the general and particular properties peculiar to building materials.

All substances around us—air, water, brick, stone, wood, etc. —are forms of matter and may be distinguished from such things as heat, light and electricity by certain properties.

The fact that **all matter occupies space** (the property of Extension) is a statement of a property which needs little elaboration; similarly with the accompanying property of Impenetrability, the statement of which is that **no two** (or more) **portions of matter can occupy the same space at the same time.**

A further property of matter is apparent when we note that, if any body be in a state of rest it will remain so unless some *force* acts upon it so as to cause it to move, or, if the body be in a state of uniform motion, e.g. a ball rolling along a smooth horizontal table, it will continue to move until some force or forces—the friction of the table top and the resistance of the air—bring it to rest. This property, in virtue of which a body is unable of itself to change its state of rest or state of motion, is known as the inertness or **Inertia** of matter; it enables us to define **Force** as *that which changes or tends to change a body's state of rest or of uniform motion in a straight line.* Particularly in considering building problems concerning force is it important to realise that forces may be acting without motion taking place; a load suspended in the air from a crane hook or a man supporting a weight are both cases where forces are producing a *tendency* to move but not actual motion. (See Chap. VI.)

All particles of matter are known to attract other particles of matter, the attractive force varying according to the *quantity of matter* contained in the particles and the *distance* separating them.

The Earth is a body so immeasurably greater than any other with which we are acquainted, that the force of attraction it exerts upon all bodies on or near its surface is the only force of this kind which we need consider. This force is known as *the attraction of gravity* and tends to cause all bodies to "fall" towards the centre of the earth. In everyday language we speak of this force as "the weight of a body" and since all forms of matter are affected in this way we may say that **all matter has weight.**

Weight and Mass. From time to time it will be necessary for us to ascertain *the quantity of matter* contained in a body. This quantity is usually referred to as **the mass of a body**. We may distinguish mass from other quantities by noting, (1) that the masses of different portions of the same substance are proportional to the spaces they occupy, and (2) that the mass of any particular body is always the same and is not affected by altering the size of the body (by compressing or otherwise). For example there is just twice as much matter in one pound of iron as there is in a half-pound of the same iron. Again if it were possible, by the exercise of great force, to compress either or both of these amounts of matter until they occupied only half the original spaces the quantities of matter would still remain unaltered. Thus it would appear that while volume is not necessarily a measure of mass it is possible to measure it by weighing, and it might be shown, more fully than space allows us to do here, that **the weight of a body gives us a measure of its mass.** The operation of weighing a body is usually carried out by means of a "pair of scales" or by a "physical balance," the body to be weighed being placed on one pan and balanced by placing on the other pan pieces of metal containing a standard quantity of matter and known as "weights." With the systems in common use the *unit of mass* is either the *pound* or the *gram.*

Practical Hints on Weighing. It will be convenient for us to refer briefly to the means at our disposal for obtaining the weights of various bodies.

The Heavy Scales. These should be used for all approximate weighing and for heavy bodies; they should for our purpose be capable of weighing anything up to 20 lbs. and sensitive enough to show a change of weight of about $\frac{1}{4}$ oz. A suitable pair of scales is shown in fig. 1.

In using such scales the points to note are:

(*a*) See that the pans are kept clean and free from dust or grease (use a soft duster).

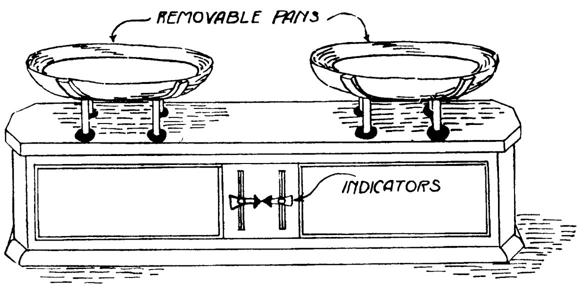

Fig. 1. The heavy scales.

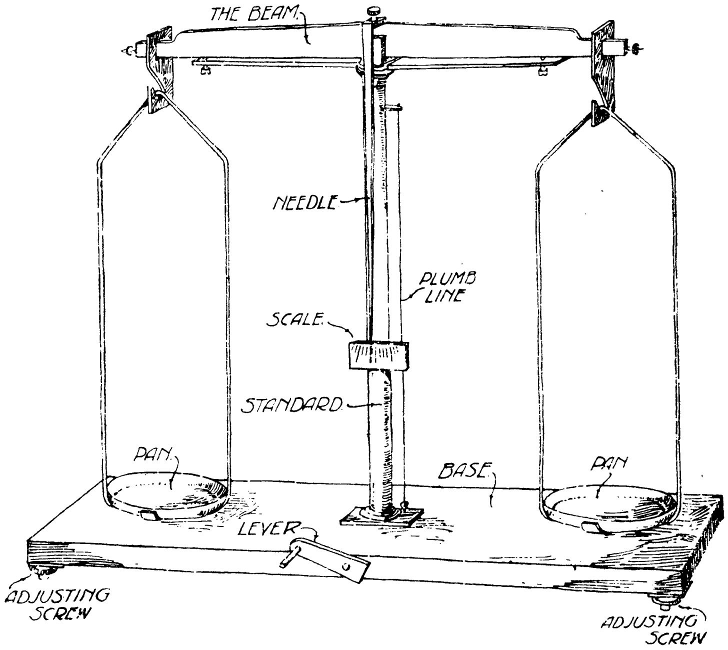

Fig. 2. The physical balance.

(*b*) Before commencing to weigh see that the empty pans balance. If there is a slight discrepancy adjust by the addition of some lead foil. If the error is considerable the scales should be corrected.

(*c*) Start your weighing with a weight that appears likely to exceed the weight of the body, then try the other weights in descending order *without omitting any*.

The Physical Balance. This is an instrument capable of a much higher degree of accuracy than the scales and it should only be used where accuracy in weighing is really essential. A suitable balance for elementary work should be capable of weighing up to 250 grams and sensitive to 5 milligrams when fully loaded. In these balances the beam and pans are suspended from delicate knife-edges. When the balance is not in use these knife-edges are freed from strain by lowering the beam on to rigid supports projecting out from the standard, see fig. 2. A small lever is provided to raise and lower the beam.

The following additional points should be noted:

(*d*) Do not place any wet or loose substance directly on the pan but always into a weighed receptacle. The weight of the substance may then be obtained by subtracting the weight of the receptacle from the total weight of substance and receptacle. This is known as the method of "difference."

(*e*) The body to be weighed is placed on the left-hand pan and the weights on the other.

(*f*) The weights must only be placed on the pan when the beam is down on the supports. To test whether the weights are correct raise the beam, keep the lever in the hand and, as soon as it is apparent that the weights are incorrect, lower the beam again. Only when it appears that a correct balance has been obtained should the lever be turned right over and the pointer be allowed to swing for some little time. If its movements on each side of the centre mark are equal then the correct weight has been found. Lower the beam again before removing the weights.

(*g*) The total of the weights should be obtained by counting them up while still on the pan and also checked by counting them again whilst they are being replaced in the box.

The Unit Weights of Building Materials. In considering the question of the weights of the various materials used in building, it will be as well to point out at once that with most of these materials, whether manufactured or natural (e.g. bricks or stones), considerable variation in weight exists; among the same batch of bricks will be found some which weigh above and others below what we may call the *average weight* of this particular kind of brick. Similarly for stones, timber, slates, etc. Hence for these materials very careful weighing is not essential. For such materials as iron, lead, zinc, cement and lime, however, much more careful weighing is necessary since their composition, and therefore their weight, is much more uniform.

Such materials as bricks, slates and tiles are used in small *units* and it is useful to know approximately the weight of each variety of these materials in the form used in building.

Similarly lead and zinc—materials largely used for covering roof surfaces—are usually described by their *weight per square foot*. If small pieces be cut off, measured and weighed, the weight per square foot may be readily calculated. For calculating roof loads or floor loads the weight *per square foot* for flooring, rough boarding, felt, slates and tiles may be similarly found.

Finally for such articles as lead piping, iron piping, rolled steel sections and timber joists the weight "*per foot run*" or per foot of length may be found experimentally by finding the weights of short lengths of each material.

It has not been thought necessary to introduce any experimental details here, as the methods to be adopted in finding the above weights are direct and simple, but a number of suggestions for adding variety to the experimental work and calculation will be found in the problems given at the end of this chapter.

Some Useful Unit Weights.

Note. Most of the following weights are only approximate. For local and special materials the reader should prepare his own list, obtaining the values experimentally as already suggested.

Material	Dimensions (inches)	Weight (lbs.)
Common Stock Brick ...	$8\frac{3}{4} \times 4\frac{1}{4} \times 2\frac{7}{8}$ (average)	$7\frac{1}{4}$
London " " ...	$8\frac{3}{4} \times 4\frac{1}{4} \times 2\frac{3}{4}$ "	$6\frac{3}{4}$
Pressed Facing " ...	$8\frac{3}{4} \times 4\frac{1}{4} \times 2\frac{7}{8}$ "	8
	to $9 \times 4\frac{1}{2} \times 3$ "	9
Common Blue " ...	$9 \times 4\frac{1}{2} \times 3$ "	$9\frac{1}{2}$
Pressed " " ...	" " " "	10 to 11
Glazed Brick	" " " "	$7\frac{1}{2}$ to 9
Welsh Slates	20×10	$3\frac{1}{2}$
Lake District Slates ...	" "	$5\frac{1}{2}$
Common Tiles	$10\frac{1}{2} \times 6\frac{1}{2} \times \frac{1}{2}$	$2\frac{1}{4}$
Pantiles	$13\frac{1}{2} \times 9\frac{1}{2} \times \frac{1}{2}$	$5\frac{1}{4}$
1 Gallon of Water ...	277 cu. ins. (approx.)	10 lbs. (at 17° C.)
Deal Boarding	1 sq. foot, 1″ thick	3
Lead	" "	59
Zinc	" "	37
Copper	" "	46
Cast Iron	" "	$37\frac{1}{2}$
Wrought Iron	" "	40
Steel	" "	41
Slab Slate	" "	15
Glass	" $\frac{1}{16}$″ thick	14 ozs.

The Densities of Building Materials. We have just found the weights of several materials taken in various units; now these weights are obviously not in such a convenient form for the comparison of various materials as they would be if we weighed an equal volume of each material every time. The quantity of matter in a unit of volume of any substance is known as the "density" of that substance; in other words, **density is the weight per unit volume.**

In expressing density we may use any units we like, but it is usual to give the weight of a cubic foot of a substance in pounds and the weight of a cubic centimetre in grams, according to the system of weights and volumes used.

Since it is not easy to obtain an exact cubic foot or an exact cubic centimetre of any substance, we must usually calculate the density from the known weight and volume of a given piece of the substance. To find the weight of a unit volume we divide the known weight by the known volume, thus:

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}}.$$

Proceeding thus find first the density of substances, such as brick, stone, wood and lead. These substances may be easily obtained in pieces of regular shape.

When the materials, of which we require the density, can only be obtained in irregularly shaped pieces then we must proceed along somewhat different lines.

Experiment 1. To find the volume of an irregular solid by displacement. We have seen that matter occupies space and that no two substances can occupy the same space at the same time; hence if a solid body be lowered into water it will *displace an amount of water equal in volume to the solid.* This is the principle of the apparatus described below and shown in fig. 3. This form of apparatus is very suitable for the fairly large specimens of materials likely to be used in a building laboratory. A smaller form of the same type of apparatus is shown in fig. 6.

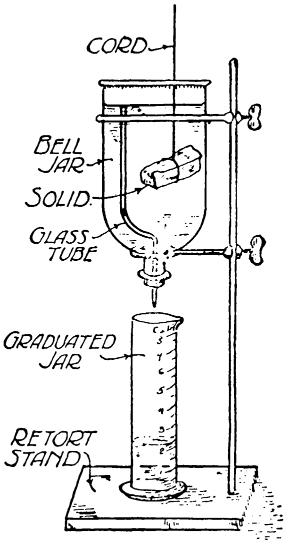

Fig. 3. Volume of a solid by displacement.

In both pieces of apparatus the vessel is filled with water until the water begins to overflow down the glass tube. When this has ceased the solid is lowered gently into the vessel and the displaced water—which evidently equals the volume of

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the solid—overflows, passes down the tube and is collected in a graduated measuring jar below. For good results the experiment should be repeated two or three times, the overflow being caught each time in the same jar. By finding the average of these results we obtain a fairly accurate estimate of the volume of the solid.

The method may be utilised to find the densities of irregular pieces of lead, zinc, iron, copper, brass, wood, stone and brick.

Porous substances like brick or stone should first be weighed then soaked for about an hour before being immersed in the bell-jar. This procedure is necessary to prevent the solid absorbing water when placed in the bell-jar. Substances, such as wood, which float in water should have a sinker of lead

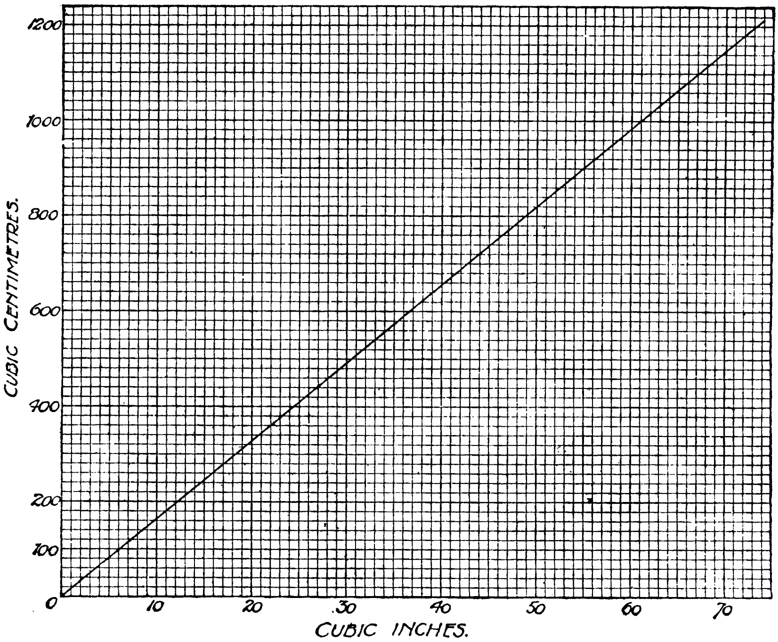

Fig. 4. Relation between cubic centimetres and cubic inches.

attached to them by a piece of string, the string being of such a length that when the sinker rests on the bottom of the jar the wood specimen is fully immersed. The solid is first suspended over the jar with the sinker *in* the water and the solid clear of the water. The level is then adjusted as already described, after which the solid is lowered and the displacement noted.

The method of recording the results of such an experiment is given below.

To find the density of Portland stone.

Weight of stone (dry) = 0·75 lb.

Stone was then immersed in water for an hour, taken out and wiped with a dry cloth.

The displaced water was collected three times and gave:

Total volume displaced = 28·35 cubic inches.

$$\text{Volume of solid} = \text{average volume displaced} = \frac{28{\cdot}35}{3} = 9{\cdot}45 \text{ cubic inches} = \frac{9{\cdot}45}{1728} \text{ cubic feet.}$$

$$\therefore \text{ Density of sample of Portland Stone} = \frac{\text{Weight}}{\text{Volume}} = \frac{0{\cdot}75}{9{\cdot}45 \div 1728}$$

= 136 lbs. (approx.) per cubic foot.

Note. If jars graduated in cubic inches are not available then a jar graduated in cubic centimetres will probably be used. In this case it will be found convenient to construct a graph similar to that given in fig. 4, by the aid of which cubic centimetres may be readily converted to cubic inches. A similar graph showing the relation between grams and pounds should also be prepared.

$$1 \text{ centimetre} = {\cdot}3937 \text{ inch (approx.)},$$
$$\therefore 1 \text{ cubic cm.} = ({\cdot}3937)^3 = {\cdot}0610 \text{ cubic inch (approx.)}$$
$$1 \text{ kilogram} = 2{\cdot}2 \text{ lbs. (approx.)}$$
$$\text{or } 1 \text{ gram} = {\cdot}0022 \text{ lb.}$$

The Density of Liquids. To obtain the density of a liquid it is only necessary to obtain *the weight of a known volume of the liquid.* A simple form of apparatus is shown in fig. 5 and consists of a flask which if filled up to a certain mark on the neck is known to contain a certain volume, say 100 cubic cms.

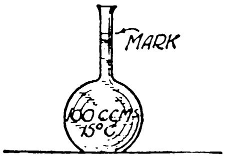

Fig. 5. Measuring flask.

Experiment 2. To find the density of water. Find the weight of the flask when empty. Then fill it with water nearly up to the mark on the flask. Take a small quantity of water into a pipette and by allowing only a drop to fall into the flask at a time, adjust the level of the water until it just reaches the mark (see p. 20). Weigh flask and water and obtain the weight of the water by subtraction. Divide the weight of the water in gms. by its known volume in cubic cms. and we have the approximate weight of water under the conditions of the experiment. This you ought to find as very nearly 1 gm. per cubic cm.

If this experiment were conducted at a temperature of 4° C. (39·1° F.) and all experimental errors were eliminated then **the weight of 1 cu. cm. would be exactly one gram.** This value is commonly used in experimental work although it is not absolutely correct at other temperatures.

By calculation it is possible to obtain the **density in lbs. per cubic ft.** (see Prob. I, 6), which at 4° C. is **62·43 lbs.** (approx.). This value will be used throughout this book so as to be consistent with the "gram per cubic centimetre" of the metric system.

For rough calculations the density is frequently taken as $62\frac{1}{2}$ lbs. per cubic foot.

Relative Density and its use in Building. In comparing the densities of various materials it would obviously be an advantage if we could take one substance as a *standard*, calling its density "1." The comparative or *relative* value of the density of any other substance would then also be expressed by a number, e.g. if it had twice the density of the standard substance its "relative density" as compared with the standard substance would be "2" and so on. We take water (strictly at a temperature of 4° C.) as our standard substance and the number which gives the ratio between the density of the substance and the density of water we call the **Relative Density** or **Specific Gravity** of the substance, so that:

$$\text{Relative Density} = \frac{\text{Density of Substance}}{\text{Density of Water}}.$$

But, since it is immaterial whether we take a cubic foot or any other volume of the substance and of water so long as we take *equal volumes*, our expression may be put in a more useful form as follows:

$$\text{Relative Density} = \frac{\text{Weight of substance}}{\text{Weight of equal volume of water}}.$$

Note. (1) We shall shortly proceed to obtain the relative density of materials in various ways, but it is most important to realise that the above expression for relative density holds good in every case no matter how the numerator and denominator of the expression are obtained.

(2) Since, as we have seen (Experiment 2), the density of water is 1 gram per cubic centimetre in the metric system and by definition its relative density is also 1, therefore the relative density of any substance in this system is given by the number expressing its weight in grams per cubic centimetre.

(3) In addition to the results obtained when ascertaining the density of a solid we require to know in this case the weight of an equal volume of water. If the volume of the solid be known in cubic cms. we have at once (from the last paragraph) the number of grams in an equal volume of water.

(4) The method usually adopted to find the volume of the solid is that of displacement, in which case "the weight of an equal volume of water" may be found directly by weighing the water displaced using the apparatus shown in fig. 3.

A very satisfactory and interesting method of dealing with this problem is based upon what is known as the **Principle of Archimedes.** This law states that **when a body is immersed in**

water (or any fluid) **it apparently loses weight, the reduction being equal to the weight of the water** (or fluid) **displaced by the body.** That this is so may readily be shown as follows.

Experiment 3. Attach a large body, such as a brick, to a spring balance. Note its weight. Now lower the brick into a pail of water. Note the sensible reduction in weight and ascertain its approximate amount by means of the balance. Calculate the weight of a volume of water equal in volume to the brick. This calculated weight and the *reduction in weight* as given by the balance should be approximately equal.

Experiment 4. To obtain a more exact verification of the law we may use the displacement apparatus already described. Fig. 6 shows it in a form suitable for finding the volume of small specimens.

The body is suspended from a special balance pan so as to hang in the displacement vessel. This is at first empty and the weight of the body is obtained when hanging thus *in air.* The body is now taken out of the vessel and the vessel filled up with water. When all the overflow has passed down the tube, a small (weighed) measuring glass is placed beneath and the body carefully lowered into the water in the larger vessel. It will now be found that the balance needs readjusting, some of the weights having to be taken off. When equilibrium has been restored note *the apparent reduction in weight.* Obtain also the weight of the water displaced and *note the approximate equality of the two weights.* Hence we have: weight of water displaced = apparent reduction in weight. It ought not to be difficult for the reader to see that this change in weight is evidently due to upward acting forces, which originally supported the water now displaced by the solid body, and these upward acting forces must be equal to the weight of the water displaced since they originally supported it.

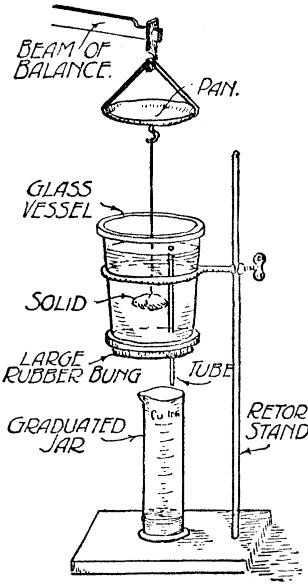

Fig. 6. Loss in weight equals weight of water displaced.

Floating Bodies. Before proceeding to utilise the above law experimentally it will be as well for us to try to realise more fully the significance of this apparent loss in weight. As we have seen, an immersed body experiences an upward force which is just equal in magnitude to the weight of the water displaced by the body. Thus we may think of two forces acting on the immersed body, the upward thrust, of which we have just spoken, and the weight of the body itself, acting vertically downwards. When the weight of the body exceeds the upward thrust the body sinks; when the weight just equals the upward thrust the body is in a state of equilibrium and will float in any position