3.1 Mass and weight

The concept of *mass* and *weight* has already been introduced in sections 7.7 and 7.8 of *Basic Engineering.*

MASS is the quantity of 'matter' or material in a component and is a constant quantity. The SI Unit for mass is the kilogramme (kg).

1 000 gramme = 1 kilogramme

1 000 kilogramme = 1 tonne

WEIGHT is the name given to the effect of the force of gravity acting on the mass of the component.

A *mass* of 1 kg equals a *weight* of 9·81 N
approximately at sea level.

Table 3.1 shows some calculations of mass and weight. For most *workshop calculations* it is normal to work on the conversion of:

1 kg mass = 10 N weight

This not only makes the problem easier to work out, it also gives a 'margin of safety'.

Table 3.1 Mass/weight conversion

MASS TO WEIGHT

1. *A steel casting has a mass of 3 810 kg. Calculate its weight in newtons (N).*

(1 kg mass	=	10 N weight [9·81 N to be more precise])		
3 810 kg mass	=	3 810 x 10		
	=	38 100 N weight		
	=	38·1 kN (kilo-newton)		

2. *A brass screw has a mass of 27 g. Calculate its weight in newtons (N).*

27 gramme	=	27 ÷ 1 000	=	0·027 kg.
0·027 kg mass	=	0·027 x 10	=	0·27 N weight.

Note how the mass in grammes had to be converted to kilo-grammes before the calculation could proceed.

WEIGHT TO MASS

3. *An aluminium casting weighs 2 850 N. Calculate its mass in kilo-gramme (kg).*

(1 N weight	=	0·1 kg mass)
2 850 N weight	=	2 850 ÷ 10
	=	285 kg mass

4. *A large machine weighs 50 kN. Calculate its mass in tonnes.*

(1 kilo-newton	=	1 000 newton)
50 kN	=	50 000 N
50 000 N	=	50 000 ÷ 10
	=	5 000 kg
1 000 kg	=	1 tonne
5 000 kg	=	5 tonne

It is useful to be able to calculate the mass and weight of components in the workshop. For example:

1. To check if lifting tackle is adequate to lift the component safety.
2. To calculate the material cost, as most raw materials are sold by 'weight'.
3. To calculate the charge of a furnace to see if there is sufficient metal to make the casting.

3.2 Density

Density is defined as *mass per unit volume.*

That is, $\text{density} = \dfrac{\text{mass}}{\text{volume}}$

For example, the density of copper is 0·008 9 g/mm^3 or, each cubic millimetre of copper has a mass of 0·008 9 gramme.

MASS = VOLUME x DENSITY

EXAMPLE: Calculate the mass of a component of volume 0·3 metre^3. The density of copper is 0·008 9 g/mm^3.

Mass = volume x density
= 0·3 x 10^6 x 0·008 9 (convert volume to mm^3)
= 2 670 gramme
= 2·67 kilo-gramme

The corresponding weight of the component would be:

weight = mass x acceleration due to gravity
= 2·67 x 9·81 (mass must be in kg)
= 26·2 newton (N)

For workshop purposes it would be accurate enough to calculate the weight as:

weight = 2·67 x 10
= 26·7 N

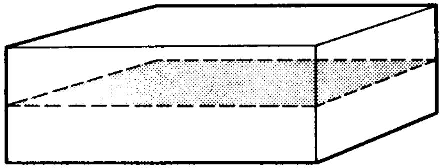
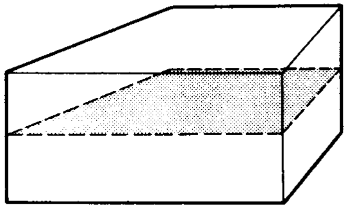
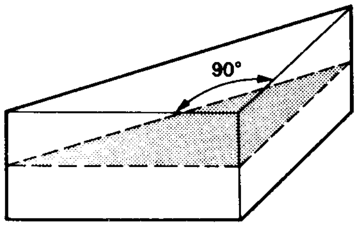
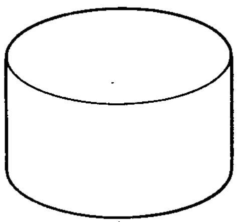
The 'error' of 0·5 N is on the right side to give a margin of safety.

Table 3.2 gives the densities for some typical engineering materials.

Figure 3.1 shows how the mass and weight of the solids given in *Basic Engineering*, table 3.23, can be calculated.

Table 3.2 Densities of common engineering materials

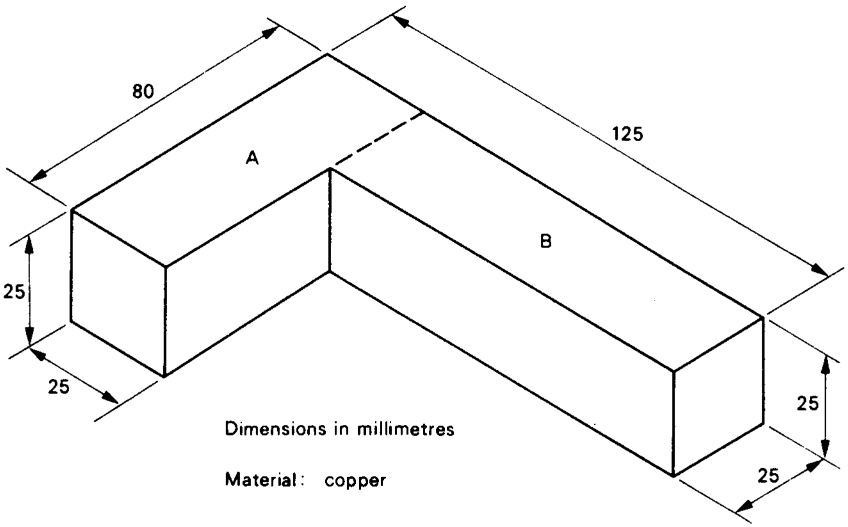
MATERIAL	DENSITY		
	g/mm^3	g/cm^3	kg/m^3
Aluminium	0·002 56	2·56	2 560
Brass (70/30)	0·008 21	8·21	8 210
Bronze	0·008 52	8·52	8 520
Copper	0·008 65	8·65	8 650
Lead	0·011 4	11·4	11 400
Steel	0·007 73	7·73	7 730
Tin	0·007 3	7·3	7 300
Zinc	0·007	7·0	7 000

SOLID	DATA	CALCULATIONS	
		MASS	WEIGHT
 Rectangular prism (copper)	Volume = 72 000 mm^3 Density = 0·008 65 g/mm^3	Mass = volume × density = 72 000 × 0·008 65 = <u>622·8 g</u>	622·8 g = 0·622 8 kg 0·622 8 kg = 0·622 8 × 10 = <u>6·228 N</u>
 Trapezoidal prism (steel)	Volume = 27 000 mm^3 Density = 0·007 3 g/mm^3	Mass = volume × density = 27 000 × 0·007 3 = <u>197·1 g</u>	197·1 g = 0·197 1 kg 0·197 1 kg = 0·197 1 × 10 = <u>1·971 N</u>
 Triangular prism (aluminium)	Volume = 300 000 mm^3 Density = 2·56 g/cm^3	300 000 mm^3 = 300 cm^3 Mass = volume × density = 300 × 2·56 = <u>768 g</u>	768 g = 0·768 kg 0·768 kg = 0·768 × 10 = <u>7·68 N</u>
 Cylinder (brass)	Volume = 4 713 000 mm^3 Density = 8 210 kg/m^3	4 713 000 mm^3 = 0·004 713 m^3 Mass = volume × density = 0·004 713 × 8 210 = <u>38·7 kg</u>	38·7 kg = 38·7 × 10 = <u>387 N</u>

Note: The volumes of these solids were calculated in Basic Engineering, table 3.23

Fig. 3.1 Calculations of volume, mass and weight

Most engineering components can be broken down into the basic shapes shown in Fig. 3.1. Figures 3.2 and 3.4 inclusive give some examples of calculations of the mass and weight of simple engineering components.



The figure can be broken down into two rectangular prisms A *and* B

1. *Volume of Prism* A

   Volume = length × breadth × thickness

   = 80 × 25 × 25

   = <u>50 000 mm³</u>

2. *Volume of Prism* B

   Volume = 100 × 25 × 25

   = <u>62 500 mm³</u>

3. *Total volume* = 50 000 + 62 500 = <u>112 500 mm³</u>

   Density of copper from table 3·2 = 0·008 65 g/mm³

4. *Mass* = volume × density

   = 112 500 × 0·008 65

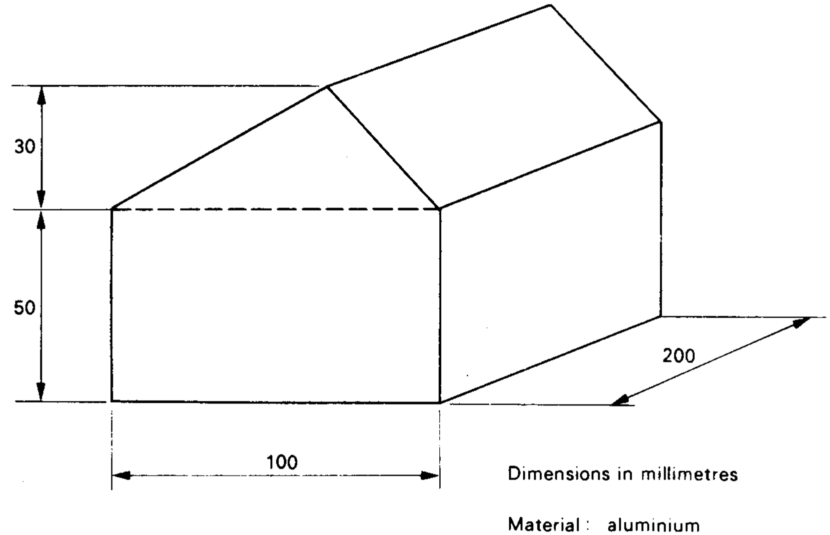
   = <u>973·125 g</u>

5. *Weight* = mass (kg) × 10

   = 0·973 1 × 10

   = <u>9·731 N</u>

Fig. 3.2 Example – volume, mass and weight (1)



The figure can be broken down into a rectangular prism and a triangular prism

1. *Volume of rectangular prism*

   Volume = length × breadth × thickness

   = 100 × 50 × 200

   = <u>1 000 000 mm³</u>

2. *Volume of triangular prism*

   Volume = ½ base × height × thickness

   = ½ × 100 × 30 × 200

   = <u>300 000 mm³</u>

3. *Total volume* = 1 000 000 + 300 000 = <u>1 300 000 mm³</u> = <u>1 300 cm³</u>

   Density of aluminium from table 3.2 = <u>2·56 g/cm³</u>

4. *Mass* = volume × density

   = 1 300 × 2·56

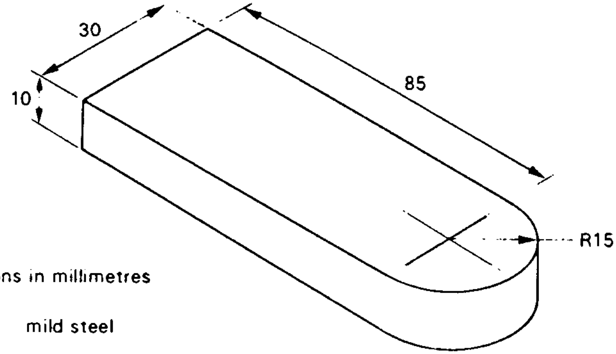
   = <u>3 328 g</u>

5. *Weight* = mass (kg) × 10

   = 3·328 × 10

   = <u>33·28 N</u>

Fig. 3.3 Example – volume, mass and weight (2)



Dimensions in millimetres

Material: mild steel

The figure can be broken down into a rectangular prism and half a right cylinder

1. *Volume of rectangular prism*

Volume = length × breadth × thickness

= 85 × 30 × 10

= <u>25 500 mm³</u>

$= \underline{25\,500\ \text{mm}^3}$

2. *Volume of half cylinder*

$\text{Volume} = \tfrac{1}{2}(\pi R^2) \times 10$

$= \tfrac{1}{2} \times 3{\cdot}14 \times 15 \times 15 \times 10$

$= \underline{3\,532{\cdot}5\ \text{mm}^3}$

3. *Total volume* = $25\,500 + 3\,532{\cdot}5 = 29\,032{\cdot}5\ \text{mm}^3$

Density from table 3.2 = $0{\cdot}007\,73\ \text{g/mm}^3$

4. *Mass* = volume × density

$= 29\,032{\cdot}5 \times 0{\cdot}007\,73$

$= \underline{224{\cdot}4\ \text{g}}$

5. *Weight* = mass (kg) × 10

$= 0{\cdot}224\,4 \times 10$

$= \underline{2{\cdot}244\ \text{N}}$

Fig. 3.4 Example – volume, mass and weight (3)

3.3 Sheet metal components

Sheet metal is often sold by *mass per unit area* for a given thickness, rather than by using volume and density. Table 3.3 gives some examples for sheets of typical engineering materials. Figure 3.5 shows how blank weights can be calculated using the data in table 3.3.

Table 3.3 Mass/unit area for sheet metal
(The values given are for mild steel. For other metals see notes.)

THICKNESS (mm) ISO R388		MASS/UNIT AREA	
1st choice	2nd choice	g/cm^2	kg/m^2
0·020		0·015 5	0·155
	0·022	0·017 0	0·170
0·025		0·019 3	0·193
	0·028	0·021 6	0·216
0·032		0·024 7	0·247
	0·036	0·027 8	0·278
0·040		0·030 9	0·309
	0·045	0·034 8	0·348
0·050		0·038 7	0·387
	0·056	0·043 3	0·433
0·063		0·048 7	0·487
	0·071	0·054 9	0·549
0·080		0·061 8	0·618
	0·090	0·069 6	0·696
0·100		0·077 3	0·773
	0·112	0·086 5	0·865
0·125		0·096 6	0·966
	0·140	0·108 2	1·082
0·160		0·123 7	1·237
	0·180	0·139 1	1·391
0·200		0·154 6	1·546
	0·224	0·173 2	1·732
0·250		0·193 3	1·933
	0·280	0·216 4	2·164
0·315		0·243 5	2·435
	0·355	0·274 4	2·744
0·400		0·309 2	3·092
	0·450	0·347 9	3·479
0·500		0·386 5	3·865
	0·560	0·432 9	4·329
0·630		0·487 0	4·870
	0·710	0·548 8	5·488
0·800		0·618 4	6·184
	0·900	0·695 7	6·957
1·00		0·773 0	7·730
	1·120	0·865 0	8·650
1·25		0·996 2	9·962
	1·40	1·082 2	10·822
1·60		1·236 8	12·368
	1·80	1·391 4	13·914
2·00		1·546 0	15·460
	2·24	1·731 5	17·315
2·50		1·932 5	19·325
	2·80	2·164 4	21·644
3·15		2·434 9	24·349
	3·5	2·744 1	27·441
4·00		3·092 0	30·920

NOTES ON USE OF TABLE

1. The mass/unit area given in the tables can be converted to the values for metals other than steel by use of the following multiplying factors.

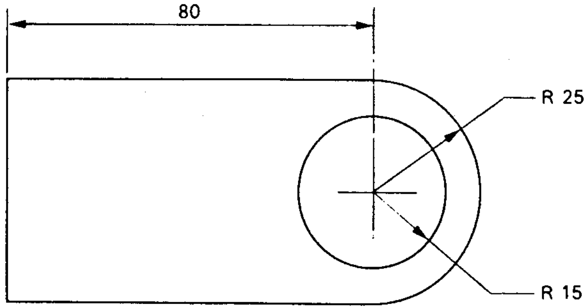
Aluminium	x 0·331 1
Brass (70/20)	x 1·062
Bronze	x 1·102
Copper	x 1·119
Lead	x 1·475
Tin	x 0·944
Zinc	x 0·906

2. To calculate the mass/unit area of 1 mm thick copper sheet.

Mass/unit area for 1 mm thick steel is 7·73 kg/m^2 multiplying factor for copper is 1·119. Therefore mass/unit area for copper 1 mm thick will be.

7·73 x 1·119

= $\underline{8{\cdot}65\ kg/m^2}$



Dimensions in millimetres

Material: 1·25mm Thick mild steel

1. Area of rectangle = 80 × 50 = 4 000mm²

   Area of semi-circle = ½ × 3·14 × 25 × 25 = 981 mm²

   Area of hole = 3·14 × 15 × 15 = 706 mm²

   Total area of blank = 4000 + 981 − 706 = 4 275 mm²

   Mass/unit area for 1·25 mm thick mild steel = 0·996 g/cm² (Table 3.3)

   Area of blank in cm² = 4 275 ÷ 100 = 42·75 cm²

   Therefore, mass of blank = 42·75 × 0·996

   = 42·6 g (mass)

   = 0·426 N (weight)

2. If aluminium sheet was used instead of mild steel, the multiplying factor × 0·3311 would have to be used (Table 3.3)

   Mass/unit area for 1·25mm thick aluminium = 0·996 × 0·3311

   = 0·329 7 g/cm²

   Therefore, mass of blank in aluminium = 42·75 × 0·329 7

   = 14·1 g (mass)

   = 0·141 N (weight)

Fig. 3.5 Calculation of sheet metal blank weights

3.4 Bar components

Bar is often sold by mass per unit length for a given cross-section, rather than by using volume and density. Table 3.4 gives some examples for bars of typical engineering materials. Figure 3.6 shows how blank weights can be calculated using the data in table 3.4.

Table 3.4 Mass/metre run for mild steel bars

CIRCULAR SECTION		SQUARE SECTION		HEXAGONAL SECTION	
Diameter mm	Mass kg	Size mm	Mass kg	Size (A/F) mm	Mass kg
4	0·098	4	0·125	4	0·107
5	0·152	5	0·194	5	0·168
6	0·200	6	0·280	6	0·240
7	0·296	7	0·380	7	0·330
8	0·390	8	0·495	8	0·430
9	0·495	9	0·630	9	0·545
10	0·610	10	0·774	10	0·670
12	0·875	12	1·13	12	0·965
14	1·190	14	1·52	14	1·34
16	1·558	16	1·99	16	1·70
18	1·97	18	2·52	18	2·00
20	2·43	20	3·10	20	2·68
25	3·80	22	3·74	22	3·24
30	5·47	24	4·47	24	3·57
35	7·45	26	5·25	26	4·53
40	9·75	28	6·08	28	5·75
45	12·3	30	6·97	30	6·05
50	15·3	32	7·91	32	6·88
60	22·0	34	8·96	34	7·79
70	29·8	36	10·3	36	8·70
80	39·0	38	11·4	38	9·70
90	49·1	40	12·4	40	10·75
100	61·0	42	13·65	42	11·85
125	95·0	44	15·00	44	13·00
150	137·0	46	16·4	46	14·4
175	186·0	48	17·9	48	15·5
200	242·0	50	19·3	50	16·8
225	308·0	55	23·4	55	20·2
250	380·0	60	28·0	60	24·1
300	549·0	65	32·6	65	28·3

Note: To use the above tables for materials other than mild steeel, use the multiplying factors given with table 3.3.

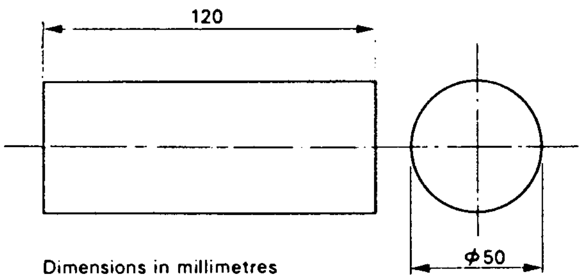
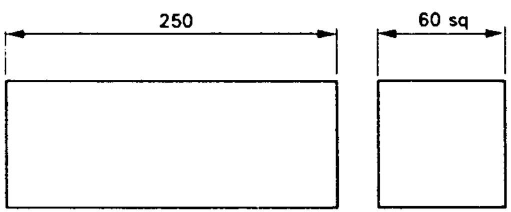
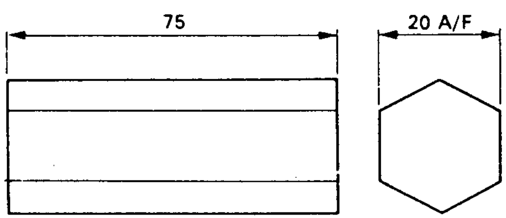
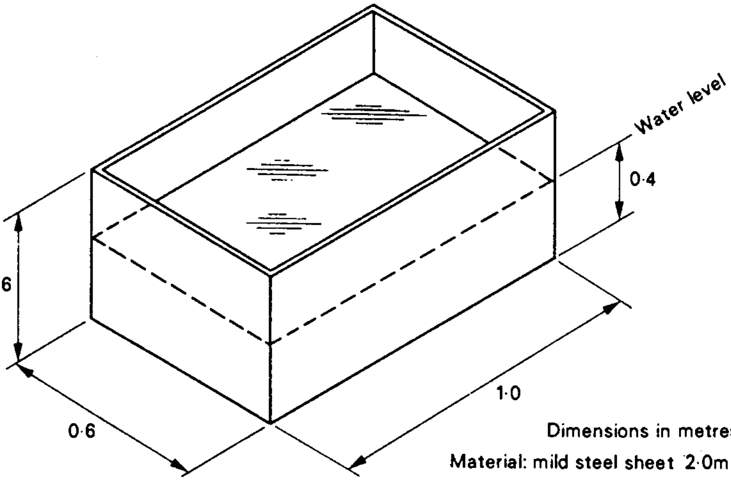
BLANK	DATA	CALCULATION
 Dimensions in millimetres Material : mild steel	Mass / metre for mild steel 50 mm diameter is 15·3 kg per metre run (table 3·4)	Length of blank = 120 mm = 0·12 m Mass / metre = 15·3 kg Mass of blank = 15·3 × 0·12 = 1·84 kg Weight of blank = 18·4 N
 Dimensions in millimetres Material : brass 70/30	Mass / metre for brass rod 60mm square is 28 × 1·062 = 29·7 kg per metre run (table 3·4)	Length of blank = 250mm = 0·25m Mass / metre = 29·7 kg Mass of blank = 29·7 × 0·25 = 7·4 kg Weight of blank = 74 N
 Dimensions in millimetres Material : aluminium	Mass / metre for hexagonal aluminium rod 20 A/F is 2·68 × 0·331 1 = 0·887 kg per metre run (table 3·4)	Length of blank = 75mm = 0·075 m Mass / metre = 0·887 kg Mass of blank = 0·887 × 0·075 = 0·067 kg = 67 g Weight of blank = 0·67 N

Fig. 3.6 Calculation of metal blank weights (bars)

3.5 Mass of the contents of a container

If the volume of a container is known and the density of the fluid or powder stored is known then the mass of the fluid or powder can be calculated as shown in Fig. 3.7.



To find the mass of the open-topped container shown together with water filled to a depth of 0·4 m

Area of sheet metal:

ends: 2 × 0·6 × 0·6 = 0·72m²
sides: 2 × 1·0 × 0·6 = 1·20m²
bottom: 1·0 × 0·6 = 0·60m²

Total area = <u>2·52m²</u>

Mass per unit area for 2·0 mm thick mild steel = 15·46 kg/m² (table 3.3)

Mass of tank = 2·52 × 15·46 = <u>38·96 kg</u>

Volume of water (allowing for thickness of sheet metal)

Volume = 0·398 × 0·596 × 0·996
= <u>0·236 2m³</u>

Density of water = 1·0g/cc

Mass of water = 1 × 0·2362 × 1 000 000
= 236 200 g
= <u>236·2 kg</u>

no	log
0·398	$\bar{1}$·5999
0·596	$\bar{1}$·7752
0·996	$\bar{1}$·9983
0·236 2	$\bar{1}$·3734

Total mass of tank and water = 38·96 + 236·2
≃ <u>275 kg</u>

Fig. 3.7 Mass of contents of container