TECHNOLOGY STUDY FILE 16

USEFUL ENGINEERING DATA

GENERAL SYMBOLS

+	Plus, positive or add
-	Minus, negative or subtract
×	Multiply
÷ or /	Divide
=	Equal(s)
≠	Does not equal
~	Approximately
≈	Approximately equal
>	Greater than
≥	Equal to or greater than
<	Less than
≤	Less than or equal to
±	Plus or minus
$\sqrt{n}$	Square root of n
$\sqrt[3]{n}$	Cube root of n

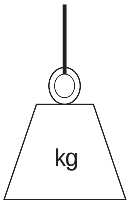
GREEK ALPHABET

(Many of these are used as symbols)

α	Α	alpha	ν	Ν	nu
β	Β	beta	ξ	Ξ	xi
γ	Γ	gamma	ο	Ο	omicron
δ	Δ	delta	π	Π	pi
ε	Ε	epsilon	ρ	Ρ	rho
ζ	Ζ	zeta	σ,ς	Σ	sigma
η	Η	eta	τ	Τ	tau
θ	Θ	theta	υ	Υ	upsilon
ι	Ι	iota	φ	Φ	phi
κ	Κ	kappa	χ	Χ	chi
λ	Λ	lambda	ψ	Ψ	psi
μ	Μ	mu	ω	Ω	omega

DECIMAL PREFIXES

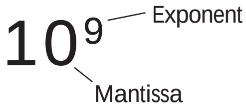
The maths and science used in technology and engineering often uses very long numbers. Instead of writing or saying these numbers, we can use several types of shorthand.



- Prefixes
  A prefix is added to the front of a unit of length or mass as a *multiplier*. 'kilo' always tells you to multiply by a thousand. 1 kilogram is a 1000 grams.

- Symbols
  Long numbers also have symbols. 'k' stands for 'kilo' or 1000. Instead of writing 0.000001 metre we can write 'μ' which is one micron (one millionth of a metre, or one thousandth of a millimetre). For example, an average human hair is 100 micron (100 μ) thick.

- To abbreviate long numbers, engineers often use *exponents* . This is a small number that tells you how many zeros the actual number contains. Many calculators now have an engineering function key that allows you to key in numbers with exponents and do maths with them. This avoids keying in - and possibly becoming confused by - very long numbers.



			Prefix	**Symbol**
10^9	= 1,000,000,000	billion	giga	G
10^8	= 100,000,000			
10^7	= 10,000,000			
10^6	= 1,000,000	million	mega	M
10^5	= 100,000			
10^4	= 10,000			
10^3	= 1,000	thousand	kilo	k
10^2	= 100		hecto	h
10^1	= 10		deca	da
10^0	= 1	1 unit		
10^{-1}	= 0.1		deci	d
10^{-2}	= 0.01		centi	c
10^{-3}	= 0.001	1 thousandth	milli	m
10^{-4}	= 0.0001			
10^{-5}	= 0.00001			
10^{-6}	= 0.000001	1 millionth	micro	μ
10^{-7}	= 0.0000001			
10^{-8}	= 0.00000001			
10^{-9}	= 0.000000001	1 billionth	nano	n

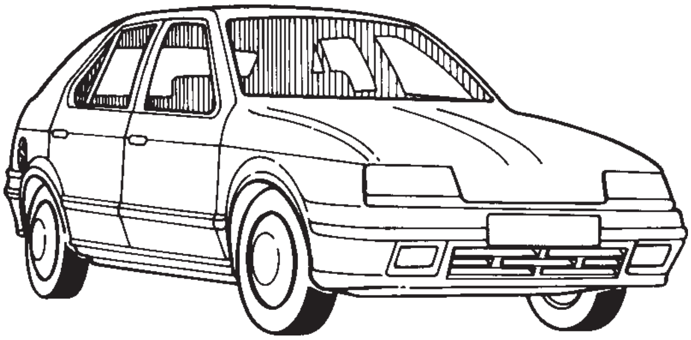
E.g.

Length:	1 <u>centi</u>metre (cm) = 1/100 metre
	1 <u>micro</u>metre (μm) = 10^{-6} metre (sometimes known as 'micron')
Weight:	1 <u>kilo</u>gram (kg) = 1000 gram
Electrical capacitance:	1 <u>micro</u>farad (μF) = 1^{-6} F

UNITS OF MEASUREMENT

Whenever we measure length, mass, time or any other quantity, we use basic units such as the metre, kilogram or second. These are examples of Systeme Internationale (SI) units which most countries have adopted. Nevertheless, you will still come across Imperial units such as inches and feet which were universally used in this country until 'metrication' in 1968 - after which time it was intended that all measurements would be in SI units. Many people, including engineers 'think' in imperial units and many measuring instruments such as simple rulers are still marked in metric and imperial.

The important thing about measurement is that the units are universal so that a metre as measured in Australia is the same as a metre as measured in Great Britain. We need to know that we are talking about the same quantities when we exchange goods, for example. In technology and engineering, it is very important that we use common standards so that when parts for something are made in different places, they fit together. Parts of cars, for example, are made in different European countries and need to fit together. The idea of interchangeable parts is based on accurate universal measurement.



The instruments we actually use to measure length are marked out or calibrated from *reference standards*. These are very accurately calibrated 'rulers'. These in turn are checked against more accurate standards until, ultimately, we check against a single primary standard. The standard metre used to be a single bar kept in a vault in Paris. This has been replaced by a definition based on the wavelength of light which can now be measured by special instruments in different places. It is worth noting that the primary standard for mass is still a block of platinum kept in a vault in Paris. There is some concern because for reasons unknown it seems to be losing 'weight' !

Table 1.1 SI (Systeme Internationale) Units

Measure	Basic Units	Symbol	Original Definition	Current Definition	Bench Mark
Length	Metre	m	1/10,000,000th of the distance between the Equator and the North Pole on the Earth's surface, measured on a line passing through Dunkirk and Barcelona	1/650,763.73 wavelengths of Krypton-86 atoms held at -210°C	Door height/ 2 metres
Mass	Kilogram	kg	Mass of one cubic decimeter of water at 4°C	Mass of prototype kilogram kept at Intl Bureau of Weights and Measures in Sevres, France	Can of soft drink 1/3Kg (0.340Kg)
Time	Second	S	1/86,400th of mean solar day	9,192,631,770 cycles of frequency generated in transition between two levels of Caesium-133	Interval in counting twen-ty-one, twen-ty-two, etc...
Temperature	Degrees (Thermodynamic)	°C		1/273.16th of the thermodynamic temperatureof the triple point of water.	Water just too hot to touch 55°C
Derived Units					
Electrical Current	Ampere (Amp)	A		Current flowing in parallel conductors 1m apart which produces a force of 2×10^{-7}N per metre of length	100 watt bulb, current flowing approx 0.4 Amps
Luminous Intensity	Candela	cd		luminous intensity of a blackbody surface area 1/60th sq cm at the solidification temp of platinum (1772°C)	

Note: The bench marks are approximate and are given as a rough guide only

Table 1.3: Imperial and Other Units

Quantity	Unit	Symbol	Equivalent to	Bench Mark
Length	inch	in	0.0254 metres	Dia of human hair, 0.004"
	foot	ft	12 inches	
Area	are	a	100 square metres	
	hectare	ha	10 000 square metres	
Capacity	gallon	gal	4.546 litres	
	US gallon	USgal	3.785 litre = 0.833 gal	
	litre	l	1 dm^3 = 1000 cm^3	
Mass	pound	lb	0.4536 kg	
	tonne	t	1 000 kg	Weight of Mini
Force	poundal	pdl	0.1383 N	
	pound force	lbf	4.4482 N	
	ton force	tonf	9.9640 kN	
	kilogram force (kilopond)	kgf(kp)	9.8066 N	
	dyne	dyn	1/100 000 Newton	
Temperature	degree Celsius	°C		Lunch time in Sahara, 50°C
	degree Fahrenheit	°F		Winter in the Yukon, -80°F
Work, energy,	British thermal unit	Btu	1.0551 kJ	
heat	IT calorie	cal IT	4.187 J	
	erg	-	10^{-7} J	
Power	horse power	hp	745.7 Watts	
Time	hour	h	3600 secs	
Pressure	pascal	Pa	1N m^{-2}	
	bar	bar	10^5 Nm^{-2}	

NB. Bench marks are provided as comparators only

CONVERSIONS

Because both the SI system and imperial system of measurements are used in different places, we often need to convert units from one to the other. Some books contain look-up tables with many equivalent numbers, but these tables often take up several pages. An alternative method of conversion is to use a calculator and multiply by a conversion figure.

For example, if you want to convert inches to millimetres you multiply the number of inches by 25.4.

3.5 inches = 3.5 × 25.4 = 88.9 mm

Using the conversion figures in table 1.4, try doing the following conversions:

1. What is 27 square yards (of carpet) in square metres?

2. What is 7 gallons (of petrol) in litres?

3. What is 0.75 litres (of vinegar) in pints?

4. What is 4 cubic yards (of cement) in cubic metres?

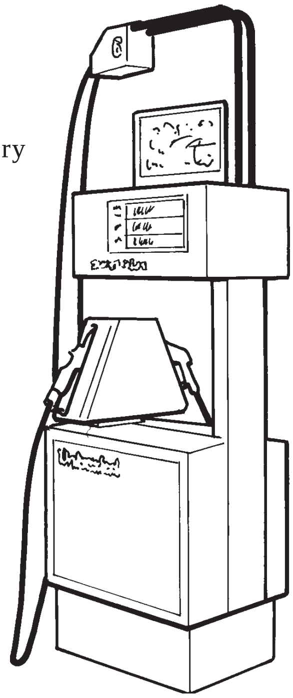


Table 1.4 **Metric and Imperial Conversions I**

	Metric = ( ) × imperial	Imperial = ( ) × metric
Area		
square miles:square kilometres	2.59	0.386
square miles:hectares	258.999	0.0039
acres:square metres	4046.86	0.00025
acres:hectares	0.4047	2.47
square yards:square metres	0.8361	1.196
square feet:square metres	0.0929	10.76
square feet:square centimetres	929.03	0.0011
square inches:square millimetres	645.16	0.0016
square inches:square centimetres	6.4516	0.155
Capacity		
gallons:cubic decimetres (litres)	4.5461	0.220
US barrels:cubic metres (for petroleum)	0.159	6.29
US gallons:cubic decimetres (litres)	3.7854	0.264
quarts:cubic decimetres (litres)	1.1365	0.88
pints:cubic decimetres (litres)	0.5683	1.76
gills:cubic decimetres (litres)	0.1421	7.04
Fuel consumption		
gallons per mile:litres per kilometre	2.825	0.354
Length		
miles:kilometres	1.6093	0.621
yards:metres	0.9144	1.094
feet:metres	0.3048	3.28
inches:millimetres	25.4	0.039
inches:centimetres	2.54	0.394
Mass		
tons:kilograms	1016.05	0.00098
tons:tonnes	1.0160	0.984
hundredweights:kilograms	50.8023	0.020
centals:kilograms	45.3592	0.022
quarters:kilograms	12.7006	0.079
stones:kilograms	6.3503	0.157
pounds:kilograms	0.4536	2.20
ounces:grams	28.3495	0.035

Table 1.5 Metric and Imperial Conversions II

	Metric = ( ) × imperial	Imperial = ( ) × metric
Velocity		
miles per hour:kilometres per hour	1.6093	0.621
feet per second:metres per second	0.3048	3.281
feet per minute:metres per second	0.0051	196.08
feet per minute:metres per minute	0.3048	3.281
inches per second:millimetres per second	25.4	0.039
inches per minute:millimetres per second	0.4233	2.363
inches per minute:centimetres per minute	2.54	0.039
Volume		
cubic yards:cubic metres	0.7646	1.308
cubic feet:cubic metres	0.0283	35.336
cubic feet:cubic decimetres	28.3168	0.035
cubic inches:cubic centimetres	16.3871	0.061

Density
1 lb/in^3 = 27.68 g/cm^3
1 lb/ft^3 = 16.02 kg/m^3

Force
1 pdl = 0.1383 N
1 lbf = 32.17 pdl = 4.448 N
1 tonf = 9.964 kN
1 kgf = 2.205 lbf = 9.807 N
1 dyn = 10^{-5} N

Power
1 hp = 550 ft lbf/s = 0.7457 kW
1 ft lbf/s = 1.356 W

Torque
1 lbf ft = 1.356 N m
1 tonf ft = 3.037 kN m

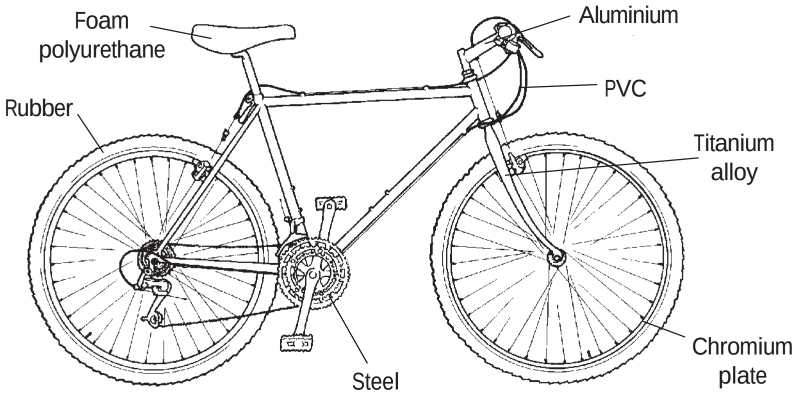
Energy, work, heat
1 ft lbf = 1.356 J
1 kW h = 3.6 MJ
1 Btu = 1.055 kJ = 252 cal$_{IT}$ = 778.2 ft lbf
1 cal = 4.187 J
1 hp h = 2.685 MJ
1 erg = 10^{-7} J

Pressure, stress
1 lbf/in^2 = 0.07031 kgf/cm^2 = 6895 N/m^2
1 tonf/in^2 = 157.5 kgf/cm^2 = 15.44 N/mm^2
1 kgf/cm^2 = 0.09807 N/mm^2 = 0.9807 bar
1 kgf/mm^2 = 9.807 N/mm^2 = 0.9807 hbar
1 lbf/ft^2 = 47.88N/m^2 = 47.88 Pa
1 ft H_2O = 62.43 lbf/ft^2 = 2989 N/m^2
1 in Hg = 70.73 lbf/ft^2 = 3386 N/m^2
1 mm Hg = 1 torr = 133.3 N/m^2
1 Int atm = 1.013x10^5 N/m^2 = 14.70 lbf/in^2
1 bar = 10^5 N/m^2 = 14.50 lbf/in^2

SI SYSTEM OF UNITS **1 Newton. metre (NM) = 1 joule = 1 watt. second**

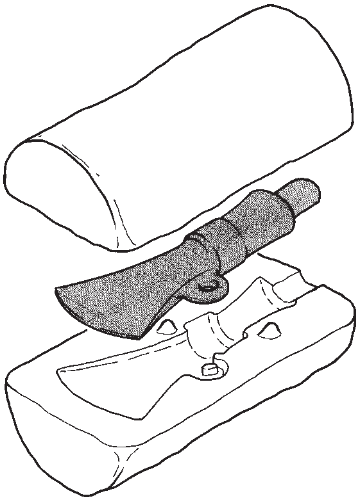
MATERIALS

Most materials used in technology are created by combining elements. These combinations may be of metals or non-metals. They may be composite materials which receive new characteristics from the various components which make them up. They may be polymers made from organic materials, such as oil, which are woven into complex structures to form the latest in 'designer' materials. A modern cycle with accessories may contain over 100 different types of material. A few are listed below.

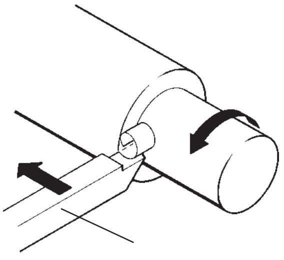


Alloys are mixtures of different metals and/or non-metals. They are not new! The Bronze Age was founded on bronze - an alloy of copper with either arsenic or tin. An alloy that offered considerable practical benefit over the copper that it replaced: it melted at a lower temperature and it produced a harder edge for cutting.

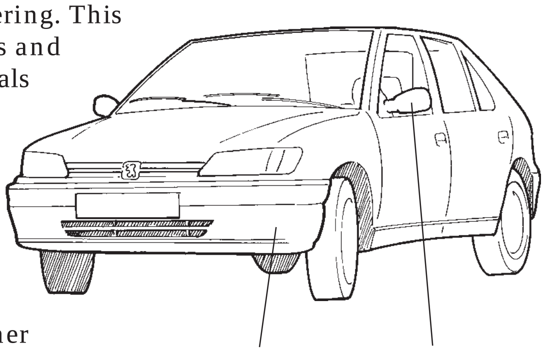
Alloys are used simply because they're better at doing some jobs than pure metals. They're often said to combine the properties of the things that make them but bronze is harder than either of the two parts that make it up. It does, however, melt at a temperature between the two.



Bronze Age axe and mould. Tin/ copper alloy



Probably the most used alloy of all is steel - a mixture of iron and carbon. However, a vast range of other materials, such as chromium, is now added to steels to form what are now known as 'alloy steels'. High speed steel (HSS) is a very hard alloy steel used in tool bits. It remains hard even at high temperatures.

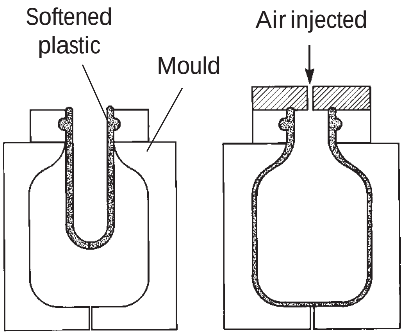


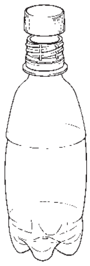
Polymers are another group of materials that find increasing application in engineering. This group includes plastics and rubber. Rubber materials are also called elastomers because of their elastic properties. Modern vehicles make use of a wide range of polymers and co-polymers. A co-polymer is a mixture of plastics that gives special characteristics.

The range of plastics in the modern world is vast and grows day by day and it is the ability of chemists and chemical engineers to create 'designer plastics' that is increasing the rate at which they replace other materials.

Polymers have been made from a range of raw materials but the most important source today has to be crude oil. This single source of hydrogen and carbon is manipulated to form the enormous family of plastics. These are tailored for each application but also for the manufacturing process as some soften when heated and others harden and stay hard. The group that softens as they become hot can be pressed or blown into a desired shape once softened and are known as thermoplastic materials. The other group, however, hardens when heated and then stays hard so any working is done cold and then the finished product fired.

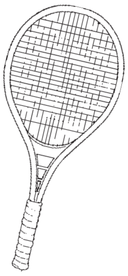
Plastic bottle being moulded



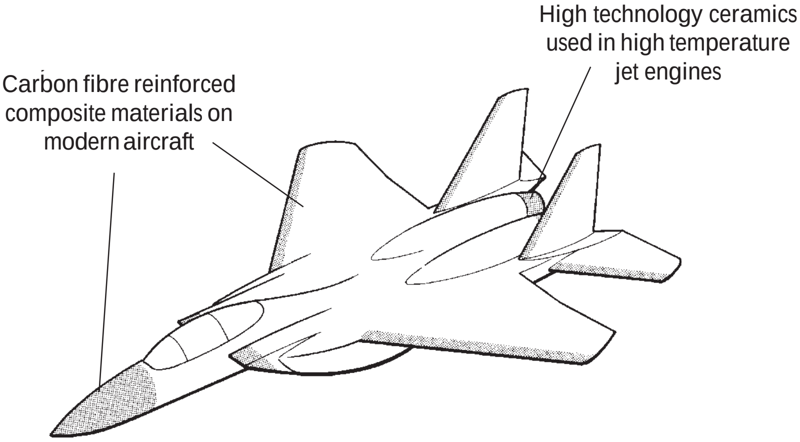


PET fizzy drinks bottle - PET stands for polyethylene teraphthalate, a co-polymer with high tensile strength

Composite materials have become important new additions to the range of materials available today. Perhaps the best known applications of these use carbon fibre, a relatively new product from a common material. When used with resins or plastic fillers, carbon fibre finds itself in products from aero engines to tennis rackets to bike frames to pressure vessels. Everywhere that its high tensile can be combined with the toughness of other material will be a place to find this combination. Many other combinations are emerging which enable the designer to tailor the composite material to the exact needs of the application.



Ceramic materials have long been an important source of raw material for manufacturing. During the Stone Age, pots were made for many uses and the technology was developed that led to the use of bricks and tiles, clay moulds for casting metals, as well as the ability to create temperatures high enough to melt metals. Ceramics are good insulators, very hard, can withstand high temperatures and today, ceramics are essential materials in many fields. Many electrical insulators are of ceramic and fireplaces, boilers and ovens all use them as thermal insulation, while manufacturing uses cutting tools made from a variety of ceramics.

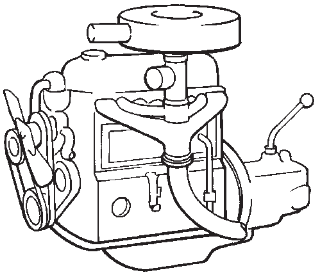


Because they too are designer materials, made up by mixing a variety of raw materials in the right proportions, ceramics find their way into applications both commonplace and exotic. They make the bricks that we live in and they coat the nose cone of the space shuttle - a much more exotic living space.

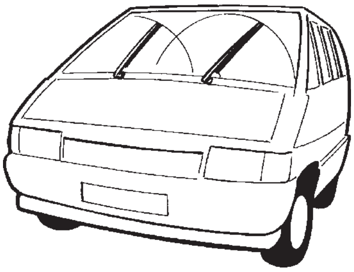
Natural materials still form an important part of raw materials in use, albeit a much less important part than in earlier times. Of these materials, wood must remain the most important, finding uses in all types of industrial and domestic products.

SOME PHYSICAL PROPERTIES OF MATERIALS

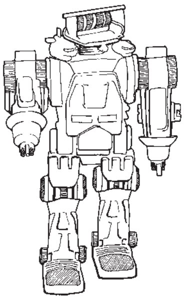
When choosing a material to do a particular job, many different properties need to be considered. Just what is important will depend very much on the application. It may be that cost is of greatest importance, it could be weight or perhaps the melting point of the material. In many cases, a number of properties need to be considered and carefully weighed up against each other. The products shown below contain many hundreds of different materials between them. Each material is carefully selected for good reasons.



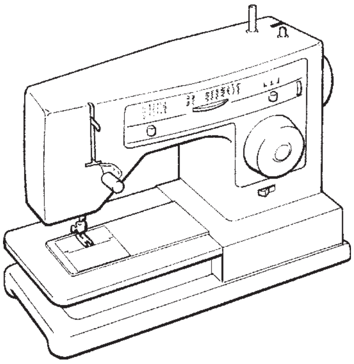
Car engine



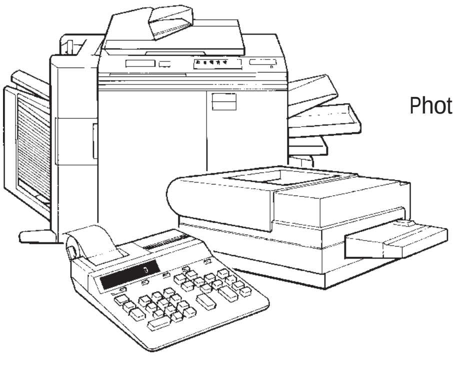
Other car components



Transformer toy



Sewing machine



Photocopier / printer / calculator

Fortunately, many properties of materials have been established by scientists and engineers and tabulated for ease of reference. These tables enable us to compare the properties of different materials and speed up the decision when setting out to choose the correct material. During the derivation of tables such as these, great care has to be taken to ensure that the experimental conditions are standardised. This means that the laboratory or equipment used must be maintained at a standard temperature and pressure (STP). The values derived must be repeatable anywhere on earth under similarly-standardised conditions. This is very important as many properties vary with temperature and/ or pressure.

The following tables list some of the important properties of materials. Not all of the information in these tables will be obvious to you, and a more advanced explanation of some of the properties appears after the tables.

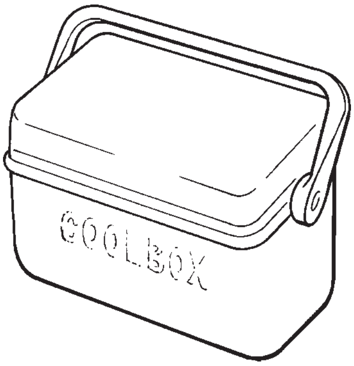
The tables are of two kinds:

- *tables that give precise numerical information to enable you, for example, to compare specific properties of materials such as hardness;*

- *tables that provide information without figures that has been reorganised for quick look-up purposes. The information on stiffness of sections (2.15) and special properties (2.16) are two examples.*

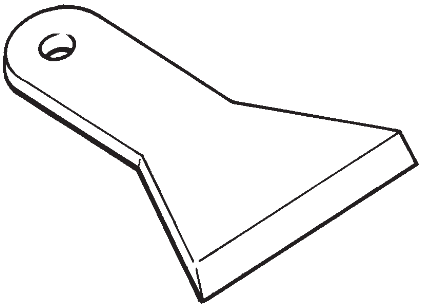
What can you learn from the tables and how will they assist you in designing and making things? When asked to produce a design specification, you need to state very clearly what your intended product has to do. You will almost certainly have to say something about its performance and this will lead you to think about suitable materials from which to make it. Here are some examples of how look-up information can help:

Example 1. The insulated container



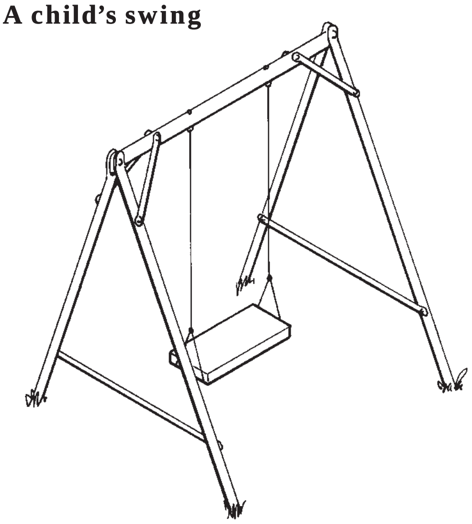
You are designing and making a small container to keep food and drink either hot or cold. What materials might be suitable for insulation ? Table 2.16 lists a number of materials that are especially good insulators. You can cross-check some of these by looking at table 2.4 which gives figures for thermal conductivity of different materials. A low figure in this table means that a material is a poor conductor of heat. We see, for example, that paper is a very poor conductor of heat and might be suitable as a cheap insulator - as it is for take-home fish and chips! It is especially good in layers because it also traps pockets of air which itself is a good insulator when not moving.

Example 2. The window scraper



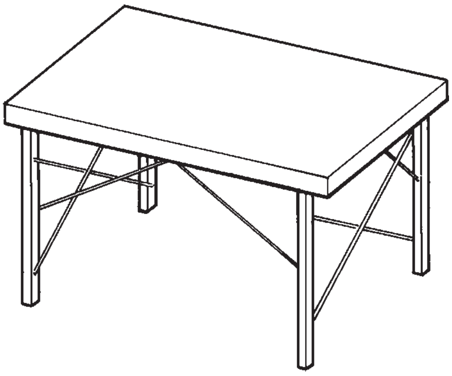
You are designing and making a small scraper to remove ice or frost from car windows and you want to make it in a single material. What will be strong enough and at the same time not scratch the window or paintwork ? Table 2.9 provides some hardness figures for metals and plastics. If the edge of the scraper is not to be worn away quickly we need a hard material but mild steel (BHN 130) is too hard because it will almost certainly scratch the paintwork. The plastics materials appear to be the most suitable ones on the list, but polythene will probably be too soft (BHN 2). Acrylic or polystyrene seem to be possibilities and you can cross-check these on table 2.14. Acrylic is the stronger material in terms of tensile strength but it is very poor for impact resistance. It will not stand up to knocks and the edge will probably chip against hard ice. Polystyrene would seem a reasonable choice of material.

Example 3. A child's swing



You are designing and making a small child's swing with a tubular metal frame whose ends are to be closed flat, drilled and bolted together. Can you use any tube for the frame? Table 2.15 reveals that a tube of large diameter for a given cross-sectional area of material is stiffer than one with a smaller diameter. (The table also provides other options such as square tube.) It is also clear that the larger diameter tube has good torsional resistance - unlike the 'I' section at the very top of the table!

Example 4. A folding table



You are looking for a suitable timber to construct a small folding table. What is the best material available to you when judged against strength and weight ? If you compare density against strength in table 2.13, you will see that spruce, although not the strongest material in the table, *is the strongest for its weight*. In fact, weight for weight, spruce is as strong as mild steel and for this reason it is still used a material in light aircraft construction.

Further, more detailed, look-up information can be found in two standard reference books available in all reference libraries:

- Kempe's Engineers Year-Book
- Newne's Engineers Handbook

Table 2.2: Some Physical Properties of Metallic Elements

Element	Mass Density Specific Gravity Kg/litre	Melting point °C	Boiling point °C	Thermal Cond. W/m°C	Coeff of Expn 10^{-6}/°C	Elect. Restvty nΩm	Main uses
Aluminium	2.7	660	2400	205	23	27	Electric Wire
Copper	6.96	1083	2580	390	178	16.8	Electric Wire
Gold	19.3	1063	2660	310	14	23	Jewellery/Elec Contacts
Iron	7.9	1535	2900	76	12	97	Castings
Lead	11.3	327	1750	35	29	206	Pipes
Nickel	8.9	1453	2820	91	13	68	Plating
Platinum	21.5	1769	3800	69	9	106	Jewellery/Elec contacts
Silver	10.5	961	2180	418	19	16	Jewellery/Photographic emulsions
Tantalum	16.6	3000	5300	54	6	135	Capacitors
Tin	7.3	232	2500	64	23	120	Surface coating
Titanium	4.5	1680	3300	17	9	550	Aircraft parts
Tungsten	19.5	3380	6000	190	4.5	55	Light Bulb Elements
Zinc	7.1	420	907	113	31	59	Surface Coating

Table 2.3: Some Physical Properties of Alloys

Alloy	Mass Density Specific Gravity Kg/litre	Melting point °C	Thermal Cond. W/m°C	Coeff of Expn 10^{-6}/°C	Elect. Restvty nΩm	Main uses
Brass	8.45	927	120	20	69	marine fittings
Constantan (60% Ni/40% Cu)	8.9	1320	22	-	490	thermocouples
Dural (4.4% Cu)	2.8	640	150	23	52	cladding of vehicles, aircraft
Manganin (84% Cu)	8.5	-	22	-	440	castings
Nichrome (80/20)	8.36	-	13	12.5	1030	resistance wire
Phosphor-bronze	8.92	1050	75	18	115	marine parts, bearings
Steel (mild)	7.85	-	50	11	120	structures

Table 2.4: Some Physical Properties of Non-Metals

Material	Mass Density Specific Gravity Kg/litre	Melting point °C	Thermal Cond. W/m°C	Coeff of Expn $10^{-6}/°C$	Elect. Restvty MΩm	Main uses
Alumina	3.9	2050	2.1	8	10^3-10^6	high temperature linings, etc.
Brick	1.4 - 2.2	-	0.4-0.8	3-9	1-2	structure & cladding in buildings
Concrete	2.4	-	1.0-1.5	10-14	-	structure & cladding in buildings
Dry ground	1.6	-	-	-	1-10	all sorts!
Glass	2.4 - 3.5	1100	0.4-1.1	3-10	5.10^3-10^6	containers, windows, insulation
Granite	2.7		2.4	6-9	-	decorative cladding, working surfaces
Mica	2.8		0.5		10^3-10^6	insulation, was used in small windows
Nylon	1.14	200-220	0.25-0.33	80-130	10^4-10^7	textiles, engineering components
Paper (dry)	1.0	-	0.06		10^4	newspapers, magazines, books
Perspex	1.2	85-115	0.19-0.23	50-80	-	models, experimental construction
Polystyrene	1.06	80-105	0.8-0.2	60-80	10^{10}	engineering components, packaging
Polythene	0.93	65-130	0.25-0.5	110-220	10^5	engineering components, packaging
PTFE	2.2	-	0.23-0.27	90-130	10^9	engineering components, non-stick surfaces
PVC (plasticised)	1.7	70-80	0.16-0.19	50-250	10^4-10^7	protection of components, clothing
Porcelain	2.4	1550	0.8-1.85	2.2	10^4-10^7	containers, insulation, heat & electrical
Quartz (crystal)	2.65	-	5-9	7.5-13.7	10^6-2×10^8	crystal oscillators
Rubber (natural)	1.1-1.2	125	0.15	200	10^7	tyres, insulation heat, electrical & vibration
Sandstone	2.4	-	1.1-2.3	5-12	-	structure & cladding in buildings
Timber (along grain)	0.4-0.8	-	0.15	3-5	-	all sorts!

Table 2.5 Some Mechanical Properties of Metals

E Young's modulus (kN/mm^2) - (linear stress)/(linear strain)*
G Shear modulus (kN/mm^2) - (shear stress)/(shear strain)* *within the elastic limits
ν Poisson's ratio - (lateral strain)/(longitudinal strain)*
σ_y Proof or yield stress (N/mm^2)
σ_f Ultimate (failure) stress (N/mm^2)

Values of σ_y and σ_f usually depend strongly on the preparation and condition of a material. The ranges given are typical but not necessarily exhaustive and, unless otherwise stated, those for metals refer to drawn or wrought rather than cast material of commercial purity.

	σ_f	σ_y	E	G	ν
Metallic elements					
Aluminium	60-160	30-140	70	26	0.34
Copper	200-350	47-320	124	46	0.35
Gold	110-230	0-210	80	28	0.42
Iron (wrought)	350	160	195	76	0.29
Iron (cast)	140-320		115	45	0.25
Lead	15-18		16	6	0.44
Nickel	480-730	140-660	205	79	0.31
Platinum	125-200	15-180	168	61	0.38
Silver	140-380	55-300	76	28	0.37
Tantalum	340-930		186		
Tin	15-200	9-14	47	17	0.36
Titanium	250-700	200-500	110	41	0.34
Tungsten	1000-4000		360	140	
Zinc	110-200		97	36	0.35

Table 2.6 Alloys

	σ_f	σ_y	E	G	ν
Alloys					
Brass (65% Cu/35% Zn)	330-530	62-430	105	38	0.35
Constantan (60/40)	400-570	200-440	163	61	0.33
Dural (4.4% Cu)	230-500	125-450	70	27	0.33
Manganin (84% Cu)	465		124	47	
Mumetal (77% Ni)	540-910		220		
Nichrome (80/20)	170-900		186		
Phosphor-bronze	330-750	110-670	100		0.38
Steel mild	480	240	210	81	0.30
Steel high yield	600	450	210	81	0.30

Table 2.7 Non-metals

	E	ν	$\sigma_{f\ (tension)}$	$\sigma_{f(compression)}$
Non-metals				
Alumina	200-400	0.24	140-200	1000-2500
Brick	10-50			69-140
Concrete	10-17	0.1-0.21		27-55
Glass	50-80	0.2-0.27	30-90	
Granite	40-70			90-235
Nylon 6	1-2.5		70-85	50-100
Perspex	2.7-3.5		50-75	80-140
Polystyrene	2.5-4.0		35-60	80-110
Polythene	0.1-1.0		7-38	15-20
PTFE	0.4-0.6		17-28	5-12
PVC (plasticized)	0.3		14-40	75-100
Rubber (natural)	0.001-1	0.46-0.49	14-40	
Sandstone	14-55			30-135
Timber (along grain)	8-13		20-110	50-100

Table 2.8 Comparative Tensile Strengths of Materials

This table gives approximate tensile strengths for a range of materials for purposes of comparison.

Material	MN/m²
steel piano wire	3000
high tensile steel	1500
titanium alloys	700 - 1400
mild steel	400
aluminium alloys	140 - 550
traditional wrought iron	140 - 280
modern cast iron	140 - 280
copper	140
brasses	120 - 400
pure cast aluminium	70
flax	700
cotton	350
silk	350
spider's thread	240
bone	140
wood (along grain)	100
tendon (muscle)	100
hemp rope	80
leather	40
glass window or wine glass	30-170
ordinary brick	5
concrete	4
wood (across grain)	3

2.9 Typical Brinell hardness numbers (BHN) for metals and plastics

Material	BHN
Soft brass	60
Mild steel	130
Annealed chisel steel	235
White cast iron	415
Nitrided surface	750
PVC rigid	20
Polystyrene	25
Acrylic (Perspex)	34
Polythene (high density)	2
Epoxy resin (glass filled)	38

2.10 Comparison of hardness numbers

Rockwell *C* scale	Vickers pyramid	Brinell hardness number	Rockwell *C* scale	Vickers pyramid	Brinell hardness number	Rockwell *C* scale	Vickers pyramid	Brinell hardness number
68	1030	–	49	515	468	30	299	286
67	975	–	48	500	458	29	291	279
66	935	–	47	485	447	28	284	272
65	895	–	46	470	436	27	277	266
64	860	–	45	456	426	26	271	260
63	830	–	44	442	416	25	265	255
62	800	–	43	430	406	24	260	250
61	770	–	42	418	396	23	255	245
60	740	–	41	406	386	22	250	240
59	715	609	40	395	376	21	245	235
58	690	594	39	385	366	20	240	230
57	670	579	38	375	356	–	220	210
56	650	564	37	365	346	–	200	190
55	630	549	36	355	337	–	180	171
54	610	534	35	345	328	–	160	152
53	590	519	34	335	319	–	140	133
52	570	504	33	325	310	–	120	114
51	550	492	32	315	302	–	100	95
50	532	480	31	307	294	–	–	–

2.11 Density of materials

In this table densities (ρ) are given for normal pressure and temperature.

Metals				Wood (15% moisture)	
Metal	ρ (kg m^{-3})	Metal	ρ (kg m^{-3})	Wood	ρ (kg m^{-3})
Aluminium	2700	Monel (67%Cu,31%Ni,2%Fe)	8900	Ash	660
Aluminium bronze	7700	Nickel	8900	Balsa	100-390
(90%Cu, 10%Al)		Nimonic (average)	8100	Beech	740
Antimony	6690	Palladium	12160	Birch	720
Beryllium	1829	Phosphor bronze	8900	Elm: English	560
Bismuth	9750	(typical)		Dutch	560
Brass (60%Cu/40%Zn)	8520	Platinum	21370	wych	690
Cadmium	8650	Sodium	971	Fir, Douglas	480-550
Chromium	7190	Steel: mild	7830	Mahogany	545
Cobalt	8900	stainless	8000	Pine: Parana	550
Constantan	8920	Tin: grey	5750	pitch	640
Copper	8930	rhombic	6550	Scots	530
Gold	19320	tetragonal	7310	Spruce, Norway	430
Inconel	8510	Titanium	4540	Teak	660
Iron: pure	7870	Tungsten	19300		
cast	7270	Uranium	18680		
Lead	11350	Vanadium	5960		
Magnesium	1740	Zinc	7140		
Manganese	7430				
Mercury	13546				
Molybdenum	10200				

2.12 Safe stresses in structural timbers (N mm^{-2})

Timber	Bending			Compression			
	Stress in extreme fibre		Horizontal shear stress	Stress parallel to grain		Stress perpendicular to grain	
	Outside location	Dry location	All locations	Outside location	Dry location	Outside location	Dry location
Oak	8.3	9.7	0.9	6.0	6.9	1.6	3.5
Douglas fir	7.6	9.0	0.6	6.0	6.9	1.6	2.1
Norway spruce	6.9	7.6	0.6	5.5	5.5	1.2	2.1

2.13 Mechanical properties of some timbers

Wood	Moisture (%)	Density, ρ (kg m^{-3})	Fibre stress at elastic limit (N mm^{-2})	Modulus of elasticity E (N mm^{-2})	Modulus of rupture (N mm^{-2})	Compressive strength parallel to grain (N mm^{-2})	shear strength (N mm^{-2})
Ash	15	657	60	10070	103	48	10
Beech	–	740	60-110	10350	–	27-54	8.3-14
Birch	9-10	710	85-90	15170	130-135	67-74	13-18.5
English elm	–	560	40-54	11790	–	17-32	8-11.3
Fir, Douglas	6-9	530	45-73	10340-15170	71-97	49-74	7.4-8.8
Mahogany	15	545	60	8690	80	45	6.0
Oak	–	740	56-87	14550	–	27-50	8-12
Scots pine	–	530	41-83	8550-10340	–	21-42	5.2-9.7
Poplar	–	450	40-43	7240	–	20	4.8
Spruce	–	430	36-62	7380-8620	–	18-39	4.3-8
Sycamore	–	625	62-106	8970-13450	–	26-46	8.8-15

2.14 Physical properties of some plastics

Properties of plastic	ρ (kg m^{-3})	Tensile strength (N mm^{-2})	Elongation (%)	E (GN m^{-2})	Impact resistance	BHN	Machinability
Thermoplastics							
PVC rigid	1330	48	200	3.4	Good	20	Very good
Polystyrene	1300	48	3	3.4	Average	25	Average
PTFE	2100	13	100	0.3	V.good	–	Very good
Polypropylene	1200	27	200-700	1.3	V.good	10	Very good
Nylon	1160	60	90	2.4	Good	10	Very good
Cellulose nitrate	1350	48	40	1.4	Average	10	Very good
Cellulose acetate	1300	40	10-60	1.4	Average	12	Very good
Acrylic (Perspex)	1190	74	6	3.0	Poor	34	Very good
Polythene (high density)	1450	20-30	20-100	0.7	Average	2	Very good
Thermosetting plastics							
Epoxy resin (glass filled)	1600-2000	68-200	4	20	V.good	38	Good
Melamine formaldehyde (fabric filled)	1800-2000	60-90	–	7	V.good	38	Average
Urea formaldehyde (cellulose filled)	1500	38-90	1	7-10	V.good	51	Average
Phenol formaldehyde (mica filled)	1600-1900	38-50	0.5	17-35	V.good	36	Good
Acetals (glass filled)	1600	58-75	2-7	7	V.good	27	Good

BHN = Brinell hardness number, ρ = density, E = Young's modulus

2.16 Special properties

Some high temperature metals

Chromium
Heat-resisting alloy steels
High speed steel
Nichrome
Nimonic alloys
Stainless steel
Stellite
Tantalum
Titanium
Tungsten
Vanadium

Corrosion resistant metals

Cupronickel
Lead
Monel metal
Nickel
Pure aluminium
Stainless steel
Tin
Titanium and alloys

Coating metals

Brass
Bronze
Cadmium
Chromium
Copper
Gold
Lead
Nickel
Platinum
Silver
Tin
Zinc

Good conductors of heat

Aluminium
Bronze
Copper
Duralumin
Silver
Zinc

Good conductors of electricity

Aluminium
Beryllium copper
Brass
Copper
Gold
Magnesium
Phosphor bronze
Silver

Good electrical insulators

Ceramics
Ebonite
Gases
Glass
Insulating papers
Mica
Shellac
Silicone rubber
Soft natural and synthetic rubber
Thermoplastics
Thermosetting plastics
Tufnol

Good heat insulators

Cork
Cotton wool
Expanded polystyrene
Felt
Glass fibre and foam
Glass wool
Hardboard
Insulating wallboard
Mineral wool
Plywood
Polyurethane foam
Rubber
Sawdust
Urea formaldehyde foam
Wood

High strength to weight ratio materials

Carbon fibre reinforced plastics
Duralumin
Glass reinforced plastics
Magnesium alloys
Nylon
Polycarbonate
Some aluminium alloys
Spruce
Titanium
Titanium alloys

FRICTION

When one surface moves against another, the resistance that opposes movement is called friction. If you push a pile of books over a table surface you can feel the friction between the table surface and the book in contact with it. Before the books start to move, there is a greater resistance. This is called *static* friction. When the books are moving, the resistance you feel is called *dynamic* (moving) friction.

If we divide the force just needed to move the books by their weight (in Newtons) we get a figure called the coefficient of friction or 'μ'. This is expressed mathematically by saying:

$\mu = F/N$ (F = force, N = weight)

The coefficient of friction for any two materials sliding against one another tells us how easily they slip against one another. The smaller the number, the less friction there is. If you look at the table below, you will see that metal on ice has a very low value - which explains why ice skates work as well as they do. Rubber on a typical road surface has the highest coefficient. Why is this important for cyclists and motorists?

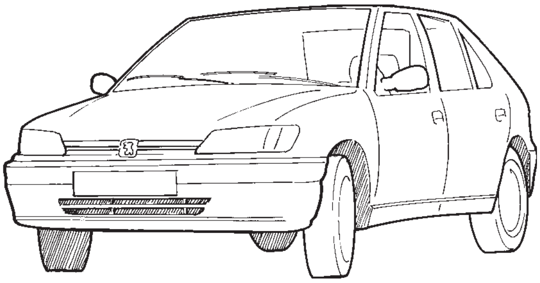


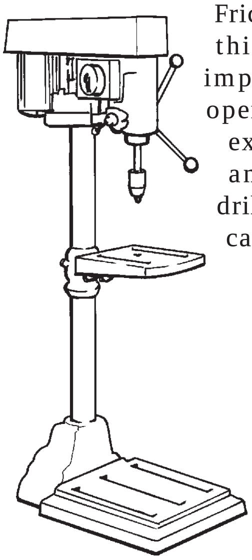
Table 2.17 Frictional characteristics of different materials

Materials	Lubrication	Approx. coefficient of friction (low pressure)
Metal on metal	none	0.20
Cast iron on hardwood	none	0.49
Cast iron on hardwood	some lubrication	0.19
Metal on hardwood	none	0.60
Metal on hardwood	some lubrication	0.20
Leather on metal	none	0.4
Rubber on metal	none	0.40
Rubber on road	none	0.90
Nylon on steel	none	0.3-0.5
Acrylic on steel	none	0.5
Teflon on steel	none	0.04
Metal on ice	–	0.02

Friction depends on:

- the force which keeps two surfaces in contact
- the roughness of their surfaces
- the materials in contact

Friction is a bad thing when it interferes with machines running. We try to reduce friction in machines such as car engines, cycles etc. We use special bearings and lubricate them well. Nevertheless, in the best machines some energy is still lost due to friction and it reappears as heat. (If a lubricated bearing dries out, it can get very hot and burn out or even melt.)



Friction is a good thing when we do not want things to slip against one another. Friction is important when we clamp things together or operate the brakes on a cycle. It is essential, for example, in transmitting power though pulleys and belts. Examples range from workshop drilling machines to the rubber belt drives in cassette players.

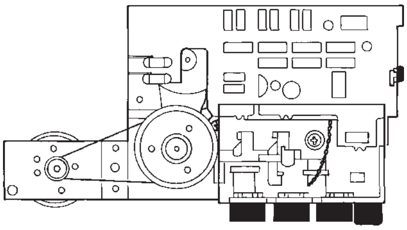


Table 2.18 gives coefficients of friction for different pairs of materials commonly used in clutches and brakes.

In any design work that you do, such tables can be used to help you decide which materials to use if you want either a lot of friction (e.g. a clamping device) or very little (e.g. a bearing). Larger engineers handbooks will give you many more combinations of materials if you need to look further.

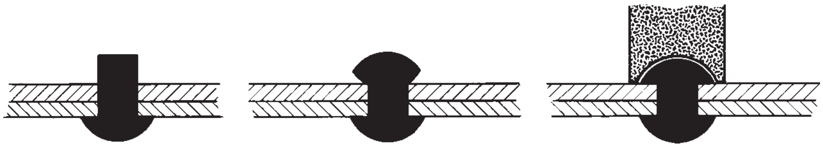
Table 2.18 Clutches and brakes

Materials	Coefficient of friction wet	dry	Maximum temperature (°C)	Maximum pressure (bar)
Cast iron/steel	0.06	0.15-0.2	250	8-13
Hard steel/hard steel	0.05	–	250	7
Wood/cast iron or steel	0.16	0.2-0.35	150	6
Leather/cast iron or steel	0.12-0.15	0.3-0.5	100	2.5
Cork/cast iron or steel	0.15-0.25	0.3-0.5	100	1
Felt/cast iron or steel	0.18	0.22	140	0.6
Vulcanized paper or fibre/ cast iron or steel	–	0.3-0.5	100	3
Moulded asbestos/ cast iron or steel	0.08-0.12	0.2-0.5	250	1
Impregnated asbestos/ cast iron or steel	0.12	0.32	350	10
Asbestos in rubber/ cast iron or steel	–	0.3-0.40	100	6
Carbon graphite/steel	0.05-0.1	0.25	500	20
Moulded phenolic plastic with cloth base/ cast iron or steel	0.1-0.15	0.25	150	7

FABRICATION TECHNIQUES

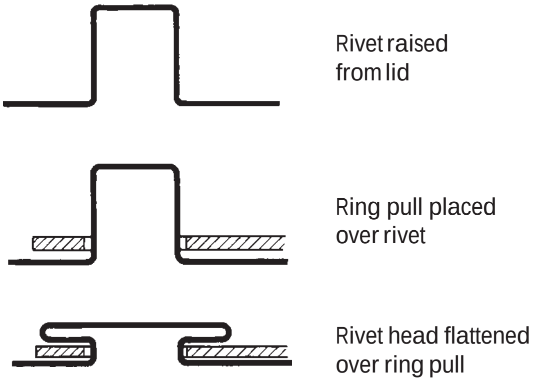
Riveting

From very early times, rivets have been used to join pieces of metal together. Rivets are still used today in many applications ranging from large scale structures to smaller domestic utensils. In its simplest form a riveted joint is created by forming a second head on a rivet directly with hammer blows or by using a rivet set to create a round head.



Stages in creating a riveted joint

Although there is a trend towards using special welding techniques in place of riveting, newer techniques have been evolved. One of these involves pressing part of one sheet through a hole in another. This is the method of joining the ring-pull onto aluminium drinks cans. A similar joining method has recently been developed that simply pushes two sheet materials together in a similar way without the initial hole!



Forming a riveted joint on an aluminium can

Welding

In a welding operation, the metal from two or more parts to be joined is melted and run together. There are five main categories of welding:

Oxyfuel Gas Welding - processes where the heat from a gas/oxygen flame is used to melt the metals involved.

Arc Welding - processes in which an electric arc is used to generate the heat necessary to melt the metals involved.

Resistance Welding - processes in which the electrical resistance of the metals involved generates the requisite heat when a current passes through them.

Solid State Welding - processes where the heat is generated internally in the metals involved by processes such as friction.

Other Processes - a range of other processes which use other physical phenomena to generate the necessary heat. An example would be the use of a laser beam or electron beam.

Oxyfuel Gas Welding

In this process, a gas is burnt in oxygen, generating an intense hot flame. Today, the gas acetylene is almost universally used giving rise to the term oxy-acetylene welding. The process is used throughout industry, as well as in the small garage to patch up old bangers, in fact almost anywhere where a low-cost welding system is required.

The flame produced has two distinct zones, the tip of the inner zone being the hottest point in the flame and the part which is generally used for welding. It is here where combustion is complete and, as all the oxygen has been consumed, the flame is neutral and will not oxidise the metals to be joined. In the outer zone the excess of acetylene causes some of the oxygen in the surrounding atmosphere to be used in combustion, thus protecting the metal from oxidation.

Arc Welding

In this process, an electric arc is created between an electrode and the work piece. The electrodes are made of metal, generally being the same material as that to be joined, and are consumed by being melted to form part of the join. In some arc welding, however, tungsten is used as an electrode and this is consumed only slowly as it evaporates.

Consumable electrodes are generally coated with a material which burns off to form a protective atmosphere around the weld. By preventing oxygen from contacting the hot weld surfaces, this considerably reduces the danger of oxidation of the weld.

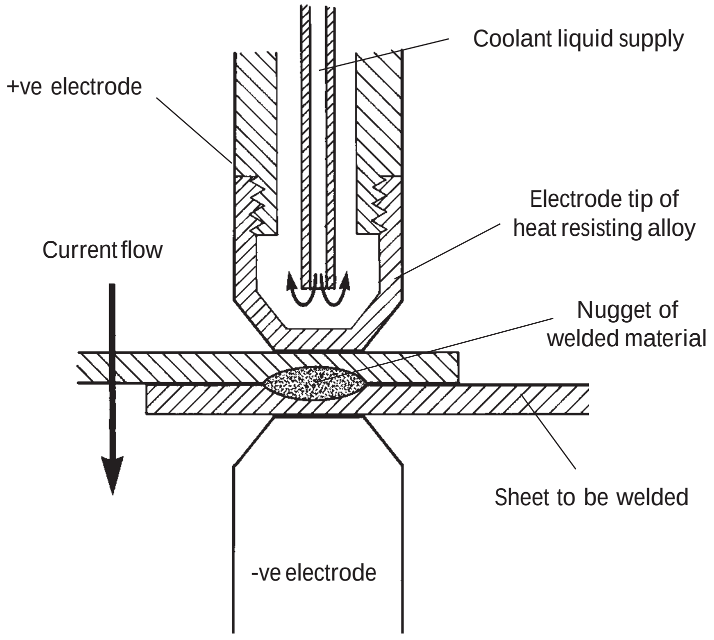
Much arc welding also utilises a gaseous shield to prevent contamination of the weld, the commonest gas used being argon - hence the term argon-arc welding.

The arc generated during welding has a temperature in excess of 3000˚C and causes a considerable glare. As with gas welding, therefore, the operator must be protected from the glare by means of a coloured screen.

Resistance Welding

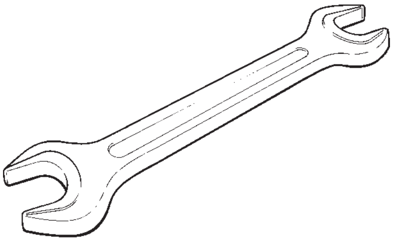
This process relies on the heating effect when a large current is passed through the material to be welded. The most common use of the technique at the present time is in spot welding and the motor car is the most common product to rely on spot welds for its structural stability.

In spot welding, a current is passed through the two metals to be joined using a pair of circular electrodes, one on each side of the sheet. These are clamped over the metal sheets while the current flows. In recent times, the job of the welder has largely been taken over by the robot and serried ranks of these line the track of car assembly plants welding together the various parts of the vehicle. The illustration below shows the general assembly of a spot welding head in use, along with the form of the finished weld.



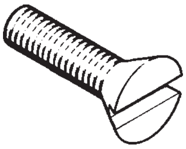
A typical spot welding head

Mechanical fastenings

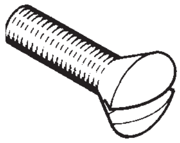


There are thousands of different types of mechanical fastening devices now available for joining metals (and dissimilar materials) together. Some of the more common of these fastenings are illustrated. They all use a screw thread which results in a very strong permanent locking force. Screws, nuts and bolts are the most common and convenient to use of all mechanical fastenings.

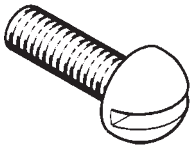
Types of fasteners



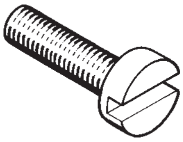
countersunk screw



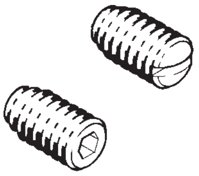
raised countersunk screw



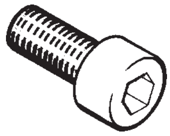
round head screw



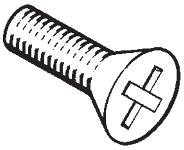
cheese head screw



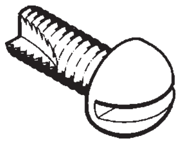
grub screws



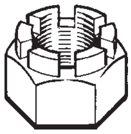
hex socket or allen head screw



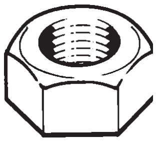
phillips or starret screw



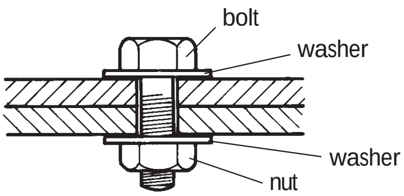
self tapping screw for plastics



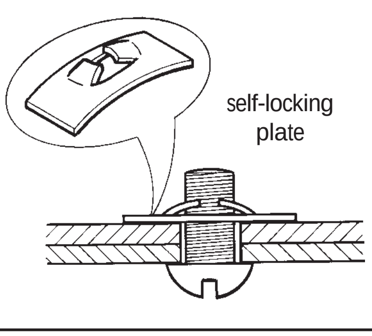
castellated nut



hex nut may be plain or with self-locking nylon insert



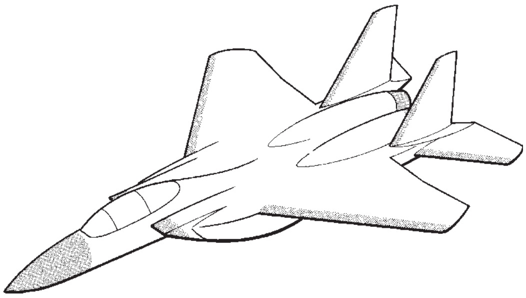
bolted assembly



self-locking plate

Adhesives

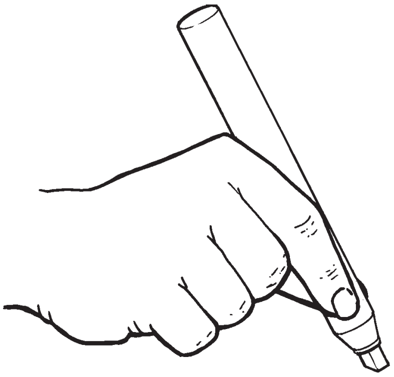
Advances in understanding materials have resulted in a huge range of new engineering adhesives. Adhesives are now used to join metals and other materials in structural applications such as aircraft where previously the method was not considered permanent or safe enough.

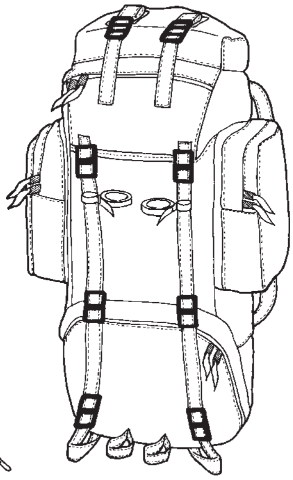


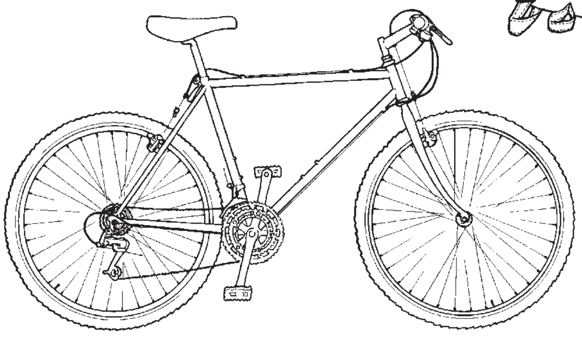
The most commonly available adhesives in the school and college workshops are epoxy resins (e.g., 'Araldite) and double-sided tapes. An enlarged range of double-sided adhesive tapes from the 3M company includes a UHB tape (ultra-high bonding) which is used currently to fasten panels on buses! Common double-sided tapes make an extremely strong joint if the surface areas to be joined are relatively large. As with any type of adhesive joint, however, the strength of the bond depends largely on the surface preparation. Any two surfaces to be joined must be chemically cleaned - e.g. with methylated spirits (which is mainly alcohol).

ERGONOMICS

Any engineer designing a product or a system will require exact information about materials, structures, tolerances, power and the capacities of various components, and how to combine them when trying to meet a specification. However, in the past designers relied on common sense when considering the needs of the people who would use and operate the products and systems they designed. The study of people in order to design products and systems which are better adapted to human capabilities is known as ***ergonomics***; it is a relatively new science.



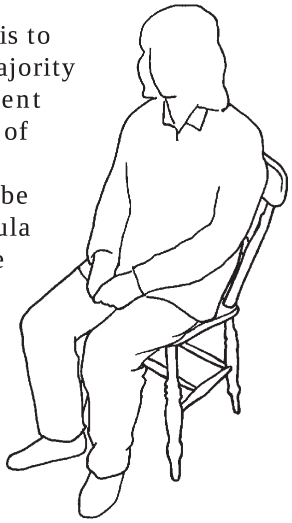




Ergonomists are employed to improve efficiency, reliability and safety. They aim to improve the design of things, such as control panels, to make them easier for people to use. An ergonomist would carry out detailed experiments to ensure, for example, that information is presented in the most appropriate way; that controls are placed within easy reach and that the force required to operate the controls is in relation to the accuracy required. Ergonomists are also concerned with the environment: the level of lighting, temperature and noise; as these are all important factors in creating good working conditions.

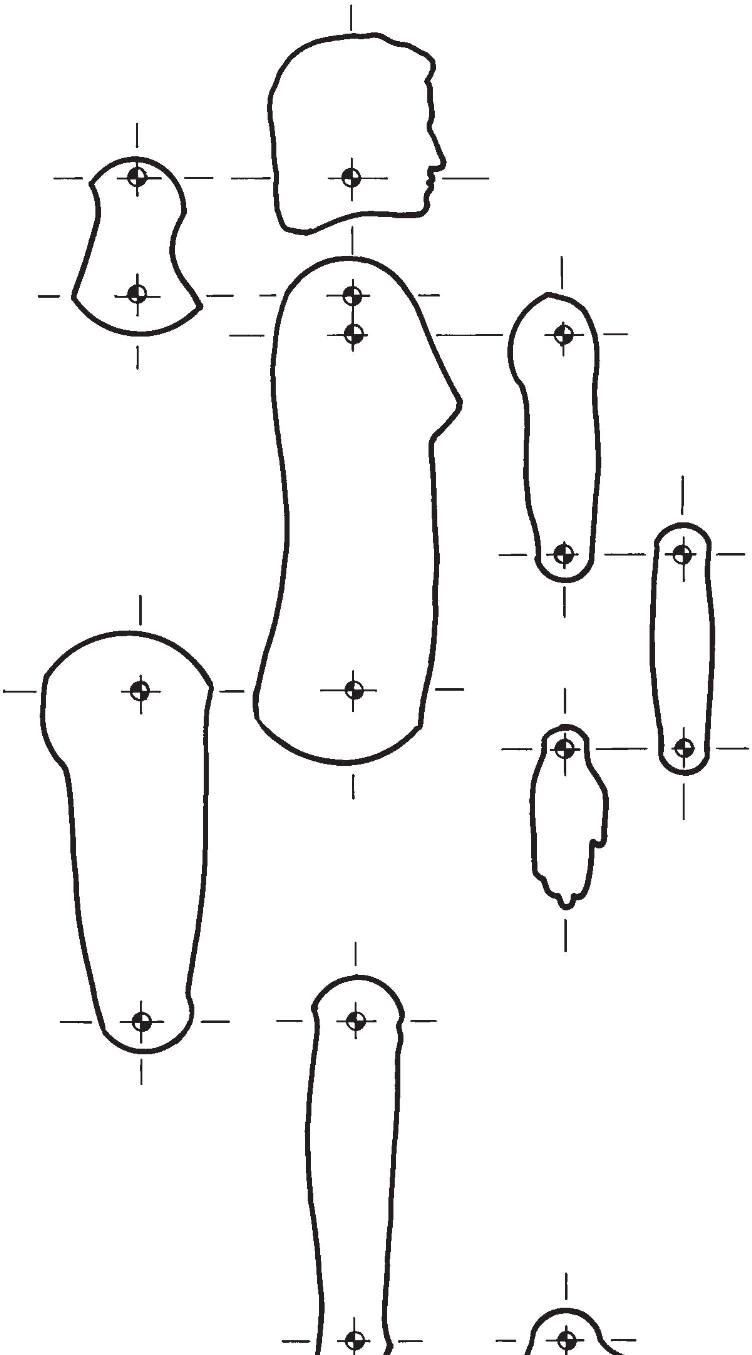
As well as trying to improve the design of new products and systems, ergonomics is also used to improve the efficiency of existing ones. It is very important to ensure that people who spend a long time in the same position do not develop painful and crippling problems such as repetitive strain injury (RSI). Computer operators, for example, sit for long periods repeating very simple movements. One way of solving the problem might be to design a better chair. Most chairs are like the ones you sit on at school, they cannot be adjusted. We have to adjust ourselves to fit the chair, this results in fidgeting, discomfort and loss of attention. Ergonomic designers believe that adjustable chairs would be better. If the operator were more comfortable, efficiency would be improved and there would be less chance of injury. To meet this need engineers have produced fully adjustable chairs, they have up to 150 moving parts and come with a user's manual for the owner!

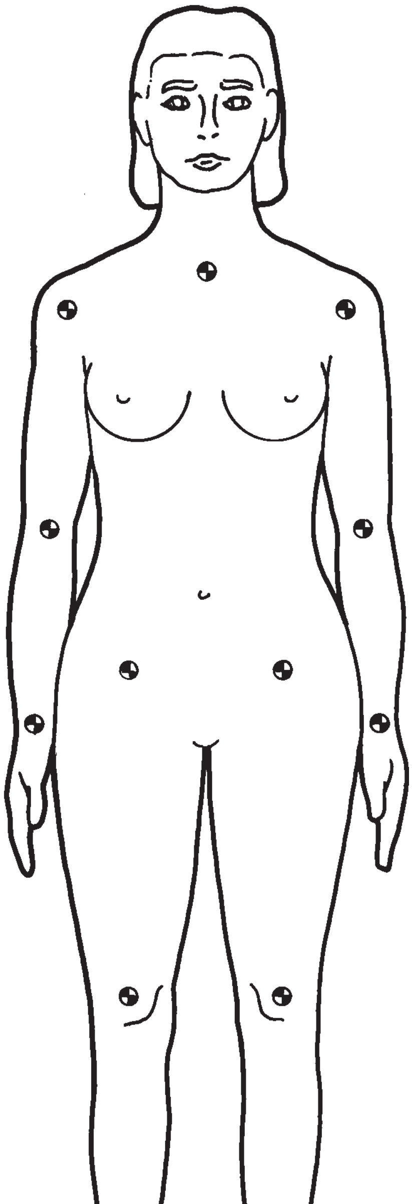
The challenge for designers and engineers is to design things which can be used by the majority of the population. Because we are all different this often means providing a limited form of adjustment. The driver's seat in a car has a number of adjustments which allows it to be customised by each driver. It is only Formula One drivers who have cockpits tailor-made to their own measurements!



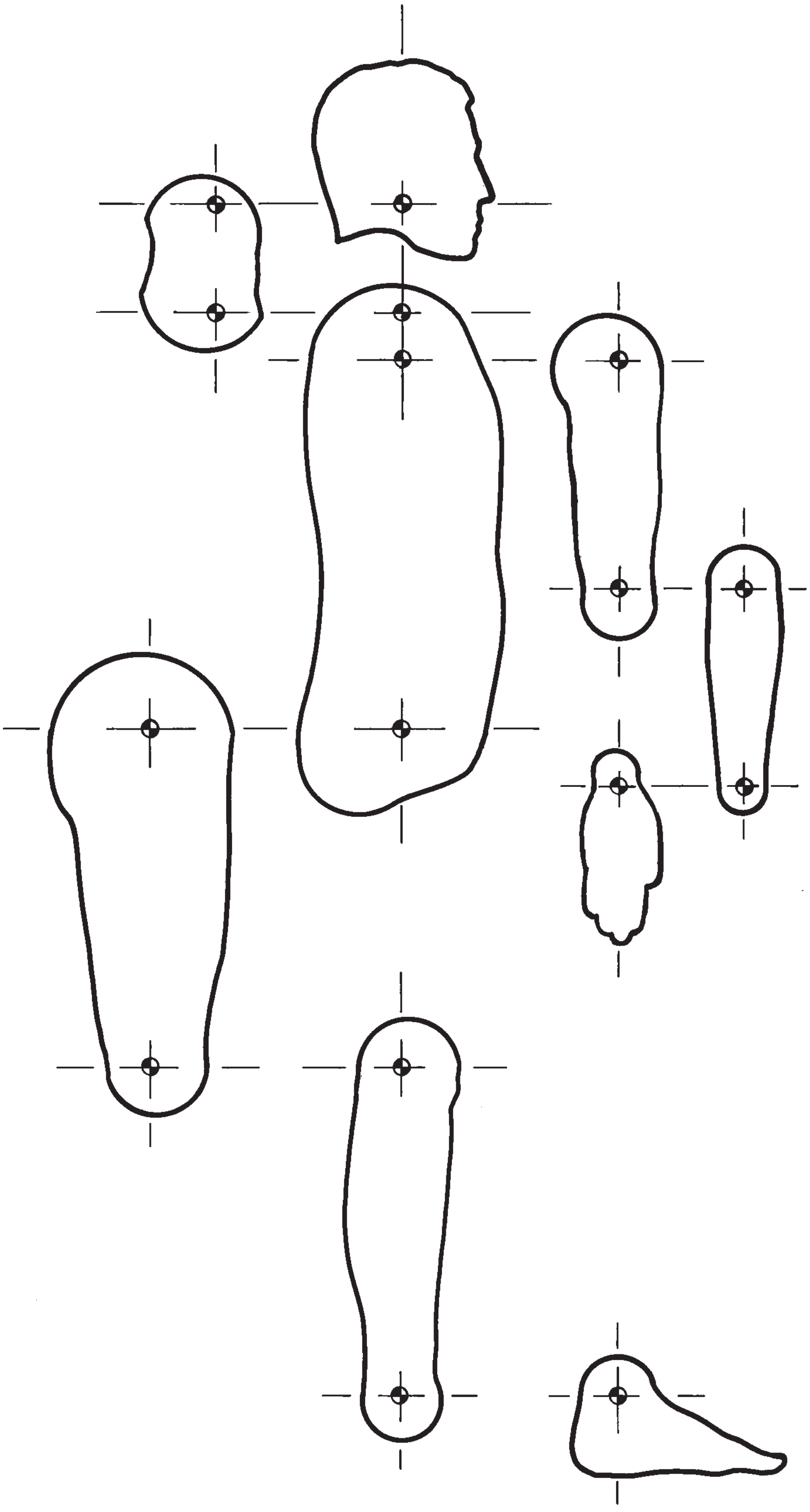
Knowing the measurements of the person or persons for whom you are designing is key to successful design. ***Anthropometrics*** is the scientific study of the measurements of the human body. ***Henry Dreyfus***, an American industrial designer, pioneered the gathering of this information; he called it human engineering. He was concerned about extreme dimensions as well as the average ones, as people come in all shapes and sizes. In addition to producing charts of the average anatomical sizes of every conceivable part of the body, he also gathered information on every conceivable aspect, such as: the amount of pressure the average foot can comfortably exert on a pedal; how hard a hand can effectively squeeze; the reach of an arm. All this information provides a very detailed picture of the average man and woman. Dreyfus called these average adults ***Joe*** and ***Josephine***. In addition he created Joe and Josephine junior, average six year olds.

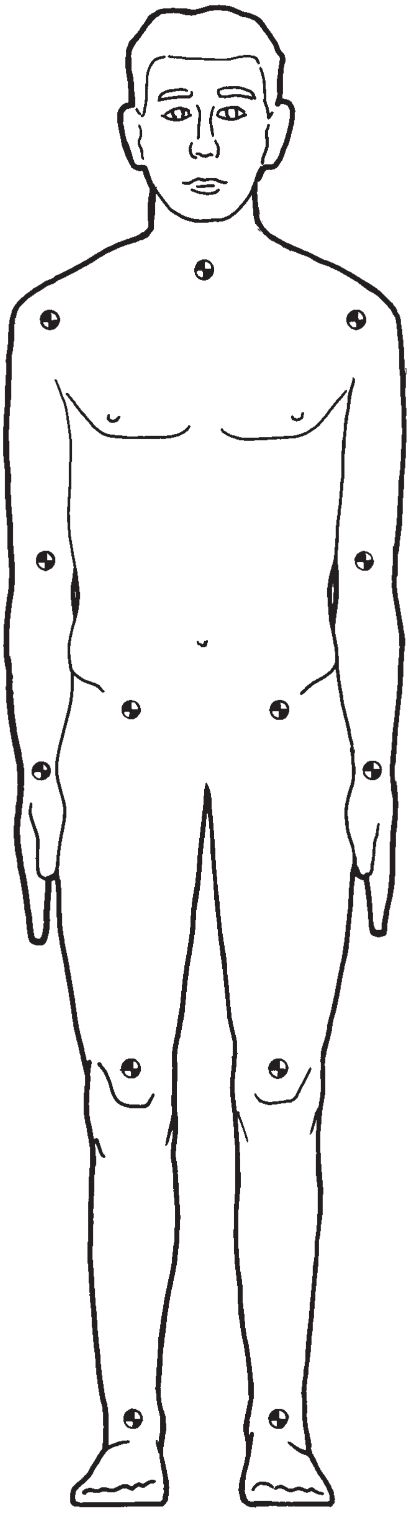
ERGONOME (FEMALE)



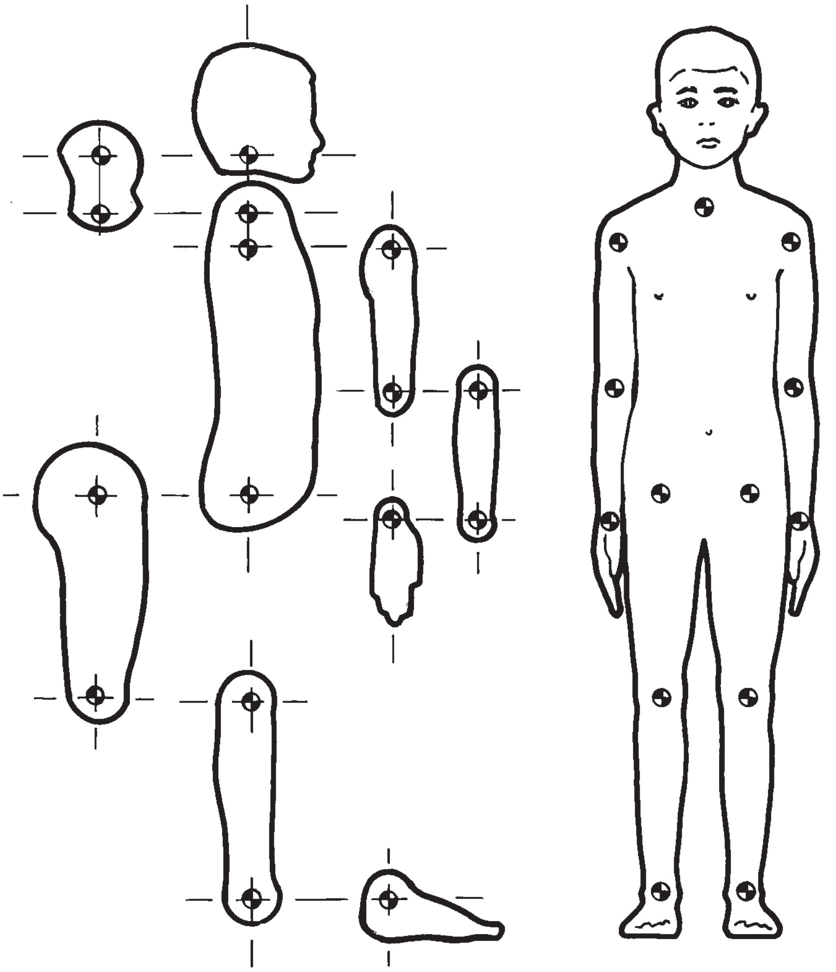


ERGONOME (MALE)



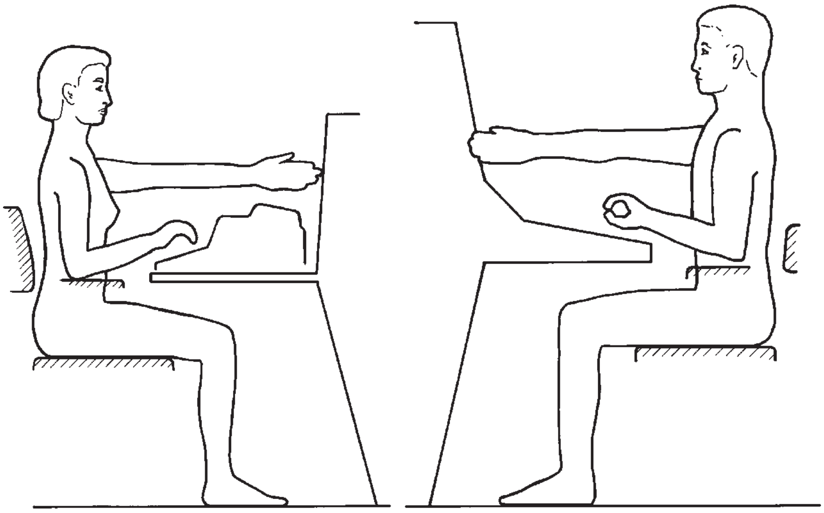


ERGONOME (CHILD)



However, ergonomic data differs between races, and changes with time. For example, some Asian races were traditionally smaller than western races. British manufactures exporting beds to Japan had to make smaller beds than those they sold in Europe. However, with improved diet, mainly increased protein intake, these races are quickly catching up. Most races are gradually getting bigger because of both better diet and health care. Look at the doorways in old houses, nowadays many people have to bend down to get through them. Currently the average height of a British male is 1753 mm and the average women is 1626 mm, four hundred years ago the average height was at least 250 mm less.

Ergonomic information can come in the form of charts, line drawings or models with pin joints, known as ***ergonomes***. If you copy the line drawings in the handbook onto card you can make an ergonome. Paper fasteners or eyelets can be used to make rotating joints or alternatively, use drawing pins and a board. An ergonome can be used to investigate the size and layout of things you are designing, like the drawings of the console/desk. If you do this you must make sure that the drawing and ergonome are to the same scale!



Models both scale and full-size could be used to investigate the layout of a working environment. A kitchen is a working environment and the position of the sink, cooker, fridge and work-surfaces relative to one another will affect efficiency. In industry people's movements are recorded using such techniques as time-lapse photography, lights attached to limbs to record movement and electronic probes fitted to prototypes. In a commercial kitchen good organisation and layout are even more important. Look at what goes on behind the counter, next time you buy a hamburger. Ergonomists have evolved a highly efficient layout so that your order is produced in the shortest possible time and is of the highest quality.

The British Standards Institution provides ergonomic information in relation to a wide variety of things. It produces a compendium for design and technology (PD 7302) which contains much useful data. For example:

- dimensions in designing for the elderly;
- design of housing for disabled people;
- play equipment for outdoors installation:
- educational furniture;
- office furniture.