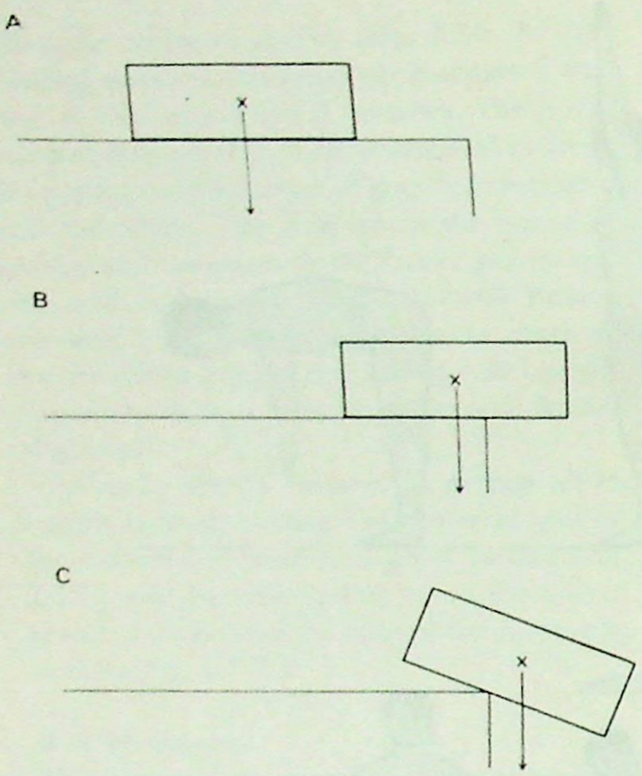

Fig. 2.27 A, Body fully supported; B, Body partially supported – the centre of gravity is over the supporting base; C, Body falls – as the centre of gravity is no longer over the base. X – centre of gravity.

The stability of a body

When a body rests on a surface its line of action must pass through its base of support. When tilted the body will fall onto the face intersected by the line of action. Thus in Fig. 2.29A, when the cube is only raised slightly, the line of action will continue to fall through the face bounded by AB. However a greater angle of raise will cause the line of action to fall through the face BC. The body will therefore fall onto this face – the structure 'falls over' (Fig. 2.29B).

The degree of stability of a body depends on two factors: base, and height of centre of gravity.

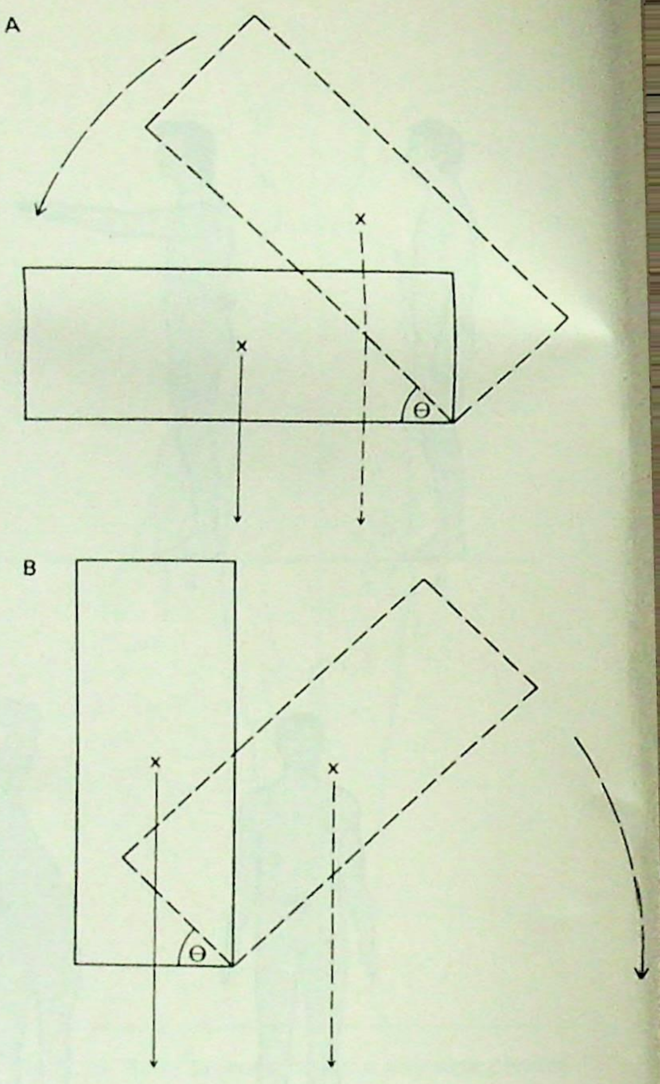

Fig. 2.28 A, Stable equilibrium – the body passes through angle θ, but falls back; B, Unstable equilibrium – the body passes through angle θ and falls over. X – centre of gravity. ↓ – line of gravity.

Base

A larger base allows greater displacement of the body without overturning.

This factor is very important when dealing with the human body. Walk standing and stride standing (Fig. 2.30A and B) increase the stability of the body in the upright position; both toddlers and the elderly spontaneously increase

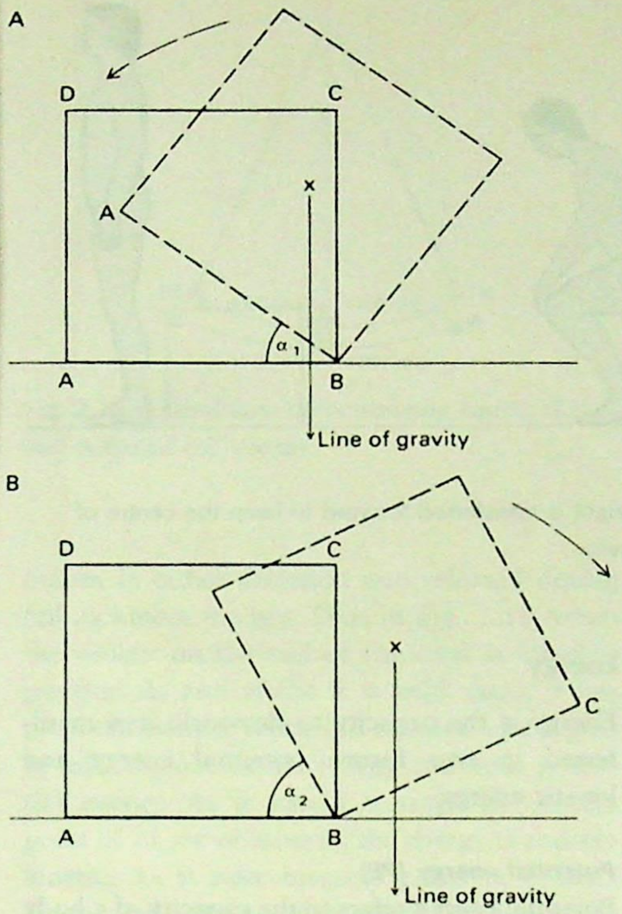

Fig. 2.29 A, The cube passes through angle α_1; the line of gravity remains through the base and the body returns to its original position; B, The cube passes through angle α_2; the line of gravity passes out of the original base and the body falls over.

their base size by widening the space between their feet and out-toeing. Walking aids such as sticks and frames have a similar effect (Fig. 2.30B). The converse is true in that a reduction in stability arises from close standing, standing on one leg and ultimately from standing on the toes (Fig. 2.30C).

Height of centre of gravity

The line of action passes through the centre of gravity. The higher this point is, the less stable the body tends to be (compare Figs 2.28A and B). The height of the centre of gravity will depend on the size and shape of the body as well as the material type and distribution. A body with most of its weight distributed towards the top will be less stable than one which has its centre of weight at a lower point. Thus standing is much less stable than sitting and lying gives ultimate stability to the human body.

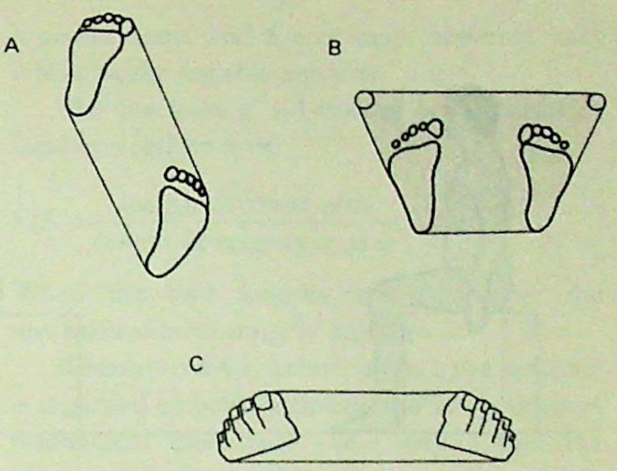

Fig. 2.30 Bases. A, Walk standing; B, Stride standing with walking aid; C, Toe standing.

A consideration of base and height of centre of gravity are of great importance when devising and progressing exercises. Raising the centre of gravity of the part and decreasing the base size will increase the difficulty of an exercise by decreasing the stability of the body and thus increasing the muscle work and co-ordination required to perform satisfactorily.

Centre of gravity and motion

It is essential for the weight of the body and thus the line of gravity to pass through the base, in order that the body weight may

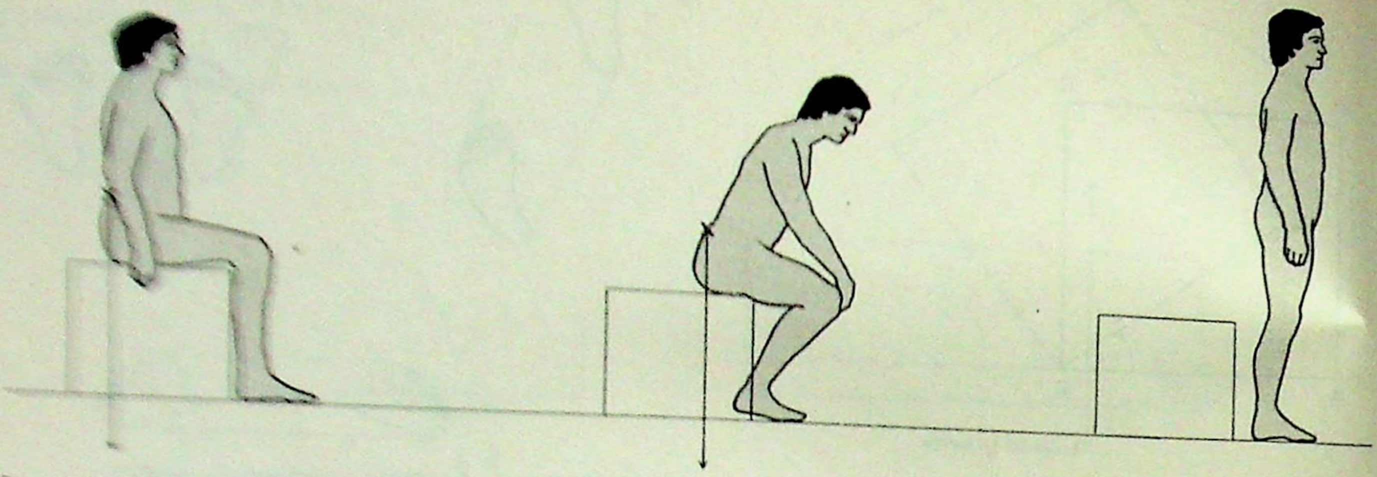

Fig. 2.31 As the body rises from sitting to standing the weight is transferred forward to keep the centre of gravity over the base. X – centre of gravity. ↓ – line of gravity.

be supported by that base. Thus it is essential for weight to be transferred over the supporting structures upon change of position. It is, for example, impossible to stand up from a chair or to climb stairs without first transferring the weight over the supporting part (Fig. 2.31). More complex movements, such as running, skipping, jumping and even cartwheels can be performed provided that control of movement of the weight of the body is achieved. Thus dynamic equilibrium is achieved.

Work, power, energy

Work

Mechanical work is done when a load is moved through a distance. The biceps brachii muscle performs work when it contracts in order to raise a load in the hand.

Power

Power is the rate at which work is done.

Energy

Energy is the capacity to do work; it is manifested in two forms: potential energy and kinetic energy.

Potential energy (PE)

Potential energy refers to the capacity of a body to do work as a result of stored energy. This stored energy may be the result of deformation of the body or the result of the position of the body. A spring held in extension is an example of potential energy resulting from deformation. An arm raised in flexion has the potential to fall under the influence of gravity and is an example of potential energy due to position.

Kinetic energy (KE)

Kinetic energy is the work performed by a body as a result of motion. Thus releasing the spring will allow work to be performed, as will allowing the arm to fall towards the floor.

The illustration in Fig. 2.32 shows the interrelationship of kinetic and potential energy during swinging. Greatest potential energy is stored at the maximum excursion of the pen-

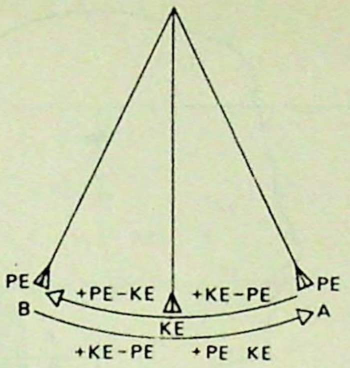

Fig. 2.32 A pendulum demonstrating kinetic (KE) and potential (PE) energy.

dulum in either direction and released during fall as kinetic energy. Thus in Fig. 2.32, when the weight on the end of the cord is lifted to position A, and whilst it is held there, it has potential energy. When it is released and begins to fall, it gains kinetic energy and loses potential energy. As it passes through the lowest point of its arc of motion, the energy is entirely kinetic. As it rises towards point B, it loses kinetic and gains potential energy until, at point B, the energy is entirely potential. The pendulum will continue to oscillate in this way until the energy originally imparted to it as a result of the work done in lifting the weight has been used up in frictional losses.

Machines

A machine is a mechanical device which does work. Those used by therapists are based on the principles of moments.

All machines are able to produce a mechanical advantage (MA), which may be either positive or negative. A mechanical advantage is a 'trade off' between effort and distance. The total force *in* must equal the total force *out* in all machines. The relative lengths of the moment arms and forces may, however, vary whilst achieving this equality.

The mechanical advantage is the ratio of *load arm* : *effort arm*:

$$\text{MA} = \frac{\text{length of effort arm}}{\text{length of resistance arm}}$$

When the two lengths are the same, the mechanical advantage is equal to 1.

When the MA is greater than 1 the machine is regarded as being efficient and has a positive mechanical advantage. This means that the effort required to shift a given resistance is less than the value of that resistance. This is possible because the total force is equal to $F \times d$. When the MA is less than 1, the machine is less efficient and exhibits a mechanical disadvantage. This means that the effort required to shift a resistance is greater than the value of the actual resistance.

Two types of machines, both based on the principles of moments, are used by the therapist – levers and pulleys.

Levers

A lever is a rigid bar which rotates about a fixed point, known as the fulcrum or axis of motion. A force is applied to the bar allowing work to be performed at some other point. Figure 2.33 represents the parts of a lever. The varying relationships between the constituent parts result in the three orders of levers.

Classification of levers

First order levers

The fulcrum is placed between the effort and the resistance (Fig. 2.34A).

When the two arms are of equal length the mechanical advantage is 1; Fig. 2.34B shows that the MA may be more than 1; Fig. 2.34C shows that the MA may be less than 1.

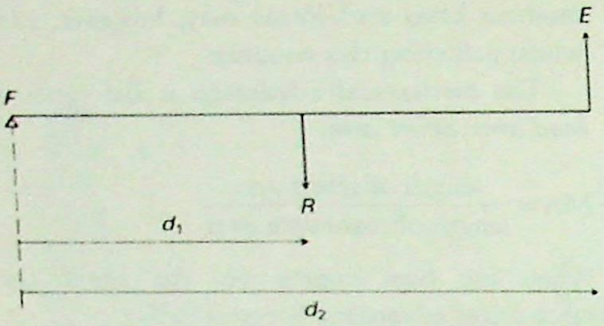

Fig. 2.33 The parts of a lever. *F* – fulcrum. *R* – resistance. *E* – effort. $d_1(F–R)$ – resistance arm. $d_2(F–E)$ – effort arm.

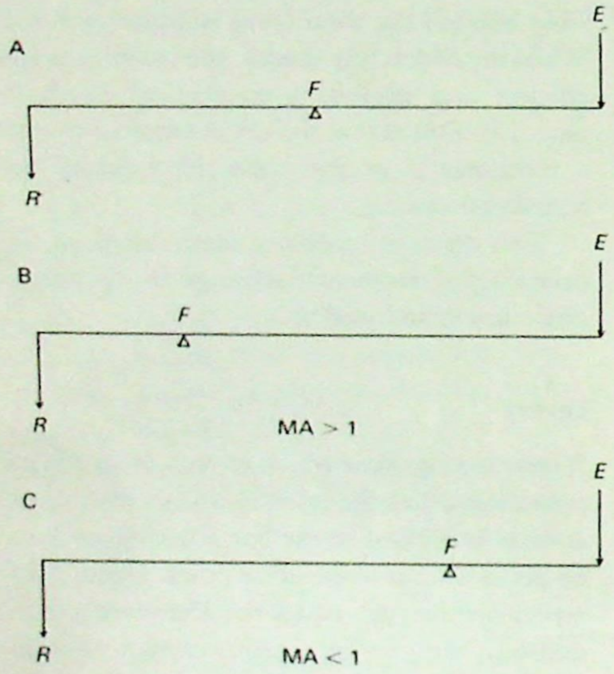

Fig. 2.34 First order lever. A, in balance – MA = 1; B, MA is greater than 1; C, MA is less than 1.

When the fulcrum is close to the resistance, a force advantage is gained. When the fulcrum is close to the effort, a force disadvantage prevails.

For example:

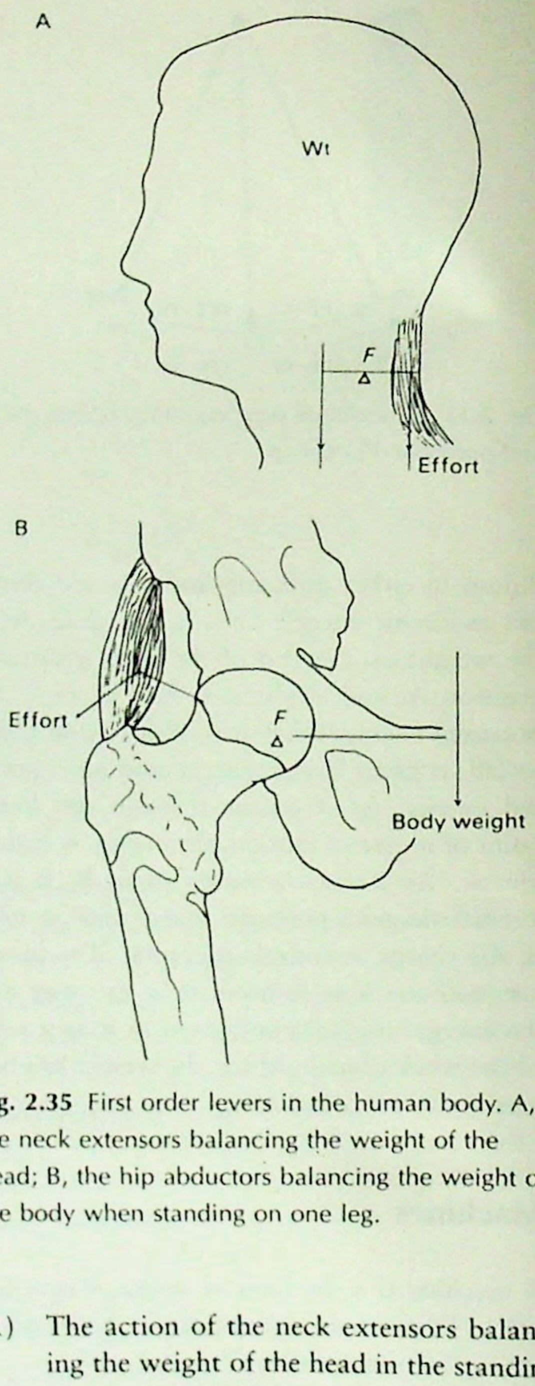

Fig. 2.35 First order levers in the human body. A, the neck extensors balancing the weight of the head; B, the hip abductors balancing the weight of the body when standing on one leg.

(1) The action of the neck extensors balancing the weight of the head in the standing position, the atlanto-occipital joint being the fulcrum (Fig. 2.35A).

(2) The action of the hip abductors about the fulcrum of the hip joint in preventing dropping of the pelvis to the unsupported side when standing on one leg. Failure of

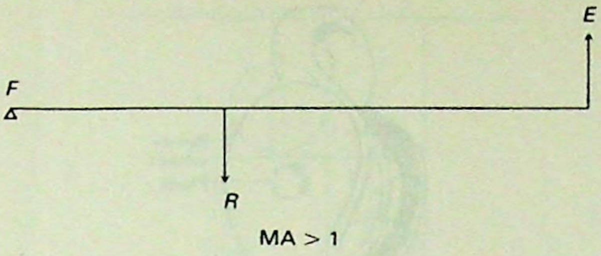

Fig. 2.36 Second order lever – the MA is greater than 1.

this mechanism leads to a Trendelenberg Sign (Fig. 2.35B).

Second order levers

The resistance lies between the fulcrum and the effort (Fig. 2.36).

The mechanical advantage is always greater than 1; a force advantage is gained. A small amount of effort can shift a large resistance.

There are few examples in the human body; the action of the muscle brachioradialis when acting as a flexor of the forearm is one example (Fig. 2.37).

Third order levers

The effort lies between the fulcrum and the resistance (Fig. 2.38).

The mechanical advantage is always less than 1; a greater amount of effort is required to shift a resistance.

Most levers in the human body are of this type:

(1) Biceps brachii acting to raise the weight of the forearm about the fulcrum of the elbow joint is one of many examples (Fig. 2.39).
(2) The hamstrings act about the knee joint, flexing the lower leg.

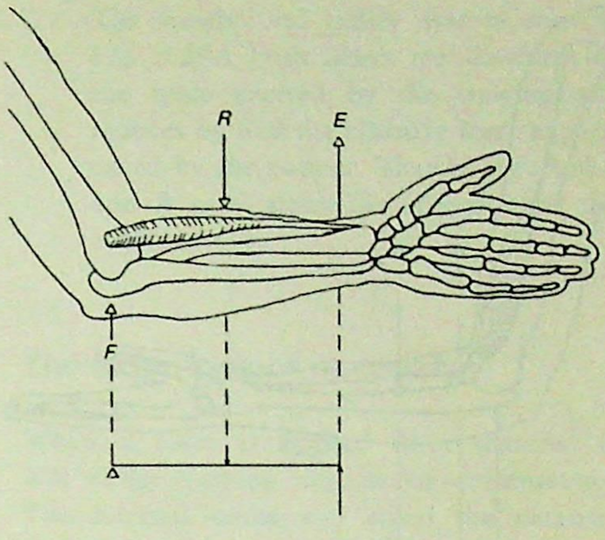

Fig. 2.37 Second order lever in the human body. Brachioradialis provides the effort, the segment weight provides the resistance and the elbow joint is the fulcrum.

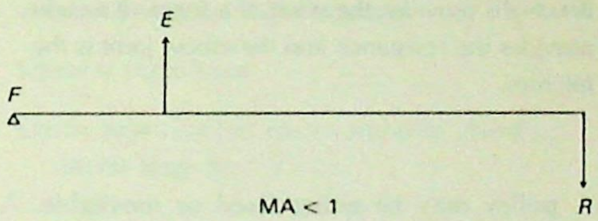

Fig. 2.38 Third order lever – the MA is less than 1.

(3) Deltoid acts about the shoulder joint in order to raise the arm.

Pulleys

A pulley consists of a grooved wheel having a rope running over it. Figure 2.40 shows an example of a pulley used by therapists in suspension therapy. A pulley may be used in order to:

(1) Change the direction of a force
(2) Obtain a mechanical advantage.

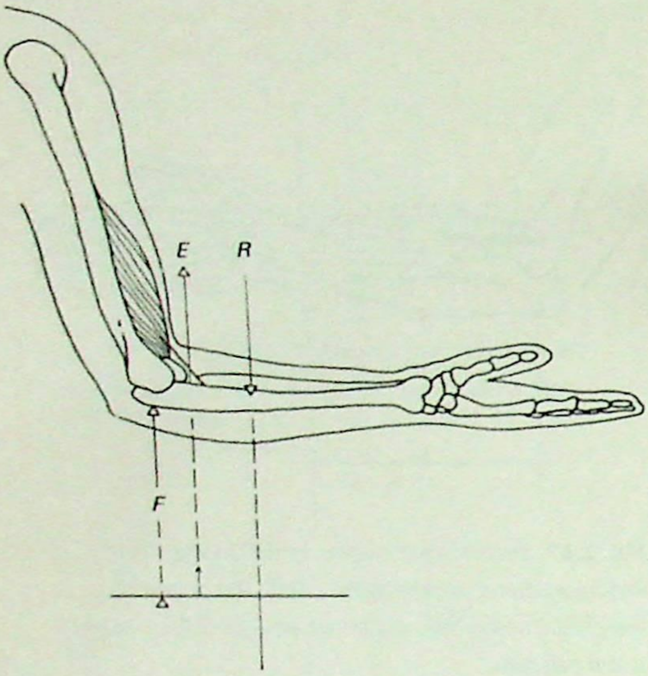

Fig. 2.39 Third order lever in the human body. Brachialis provides the effort, the segment weight provides the resistance and the elbow joint is the fulcrum.

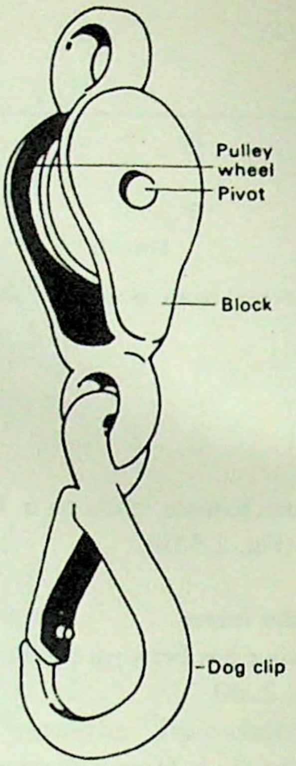

Fig. 2.40 A pulley.

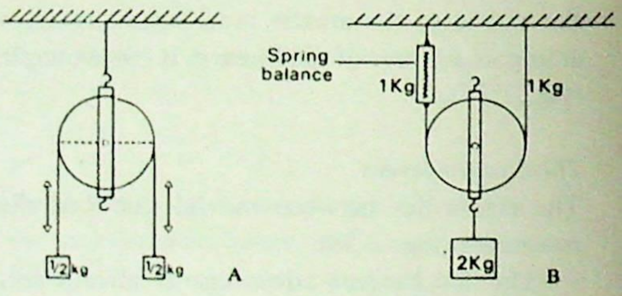

Fig. 2.41 A, A pulley demonstrating that it serves to change the direction of the force; B, A pulley suspended to show how the load is distributed at the suspended points.

A pulley may be either fixed or moveable. A fixed pulley will only change the direction of a force; a moveable pulley can also obtain a mechanical advantage.

A single fixed pulley has a mechanical advantage of one as the load on the pulley wheel requires an equivalent force to allow it to be balanced. Such a pulley serves to change the direction of the force which must be applied in order to move the load (Fig. 2.41A). Use is made of this simple device in the reciprocal pulley circuits described in Chapter 9 and also in the rope and pulley circuits which allow combined oblique and rotary movements.

A multiple pulley circuit offers a greater mechanical advantage than a single pulley. This is demonstrated if a pulley with a weight attached is inverted and hung from a hook in the ceiling by a cord, and a spring balance is inserted into the cord circuit to measure the force (Fig. 2.41B). Each side of the cord takes half the weight and therefore the mechanical advantage of the circuit will be two.