33 Doing Work, Potential Energy and Power

Doing work always requires a force. However, applying a force does not necessarily mean that work is done.

A force does need an energy supply if the force's point of application is moving (unless the motion is at right angles to the force).

Example of a force which does require an energy supply:
Thrust from jet engine.

Example of a force which does not require an energy supply:
The weight of a book sitting on a table.

If the force is in the same direction as the motion, the force does work on the object and the object will speed up (unless other forces act).

If the force on the object is in the opposite direction to its motion, the object does work and it will slow down (unless other forces act).

When work is done, one energy store will decrease, and another will increase. Work is measured in joules (J) - the same unit as energy.

If the force is perpendicular to the motion, the object neither slows down nor speeds up. No work is done, and there is no energy transfer. However, the object will change direction and accelerate.

$$\text{work done} = \text{force} \times \text{distance moved parallel to force}$$

$$W = Fs$$

$$\text{Energy Transfer, } E = \text{Work Done, } W$$

So, lifting a 1 N weight 1 m upwards requires work of 1 J.
Lifting a 1 N weight 2 m upwards requires work of 2 J.
Lifting a 2 N weight 2 m upwards requires work of 4 J.
Lifting a 10 N weight 4.0 m upwards onto a shelf, and then sliding it sideways by 2.0 m against a friction force of 2.5 N requires work of $40 + 5 = 45$ J.

The energy change each second is called the power, measured in watts (W).

$$\text{power} = \text{energy transfer} / \text{time}$$

$$P = \frac{E}{t} \quad \text{or} \quad P = \frac{W}{t}$$

Example 1 – Calculate the power needed to push a car 12.5 m along a road with a force of 2 340 N in 15.0 s.

Work done $= Fs = 2\,340$ N $\times$ 12.5 m = 29 250 J
Power $= W/t = 29\,250$ J/15.0 s $= 1\,950$ W

Example 2 – Calculate the energy transfer when a 20 kg sack of flour is winched 13.5 m upwards in a mill.

Force = weight = mass $\times g = 20.0$ kg $\times$ 10 N/kg = 200 N
Work done $= Fs = 200$ N $\times$ 13.5 m = 2 700 J

Notice that the work done during lifting equals the increase in gravitational potential energy.

$$\text{gravitational potential energy (GPE)} = \text{mass} \times g \times \text{height}$$

$$E = mgh$$

33.1 Complete the table below, where each row is a separate question. The units are in the heading except in the cases where they are stated.

Force (N)	Distance (m)	Work (J)	Time (s)	Power (W)
4.5	8.2	(a)	10.0	(b)
(c)	30.0	12 000	(d)	7 200
650	75 cm	(e)	0.63	(f)
2 500	12.0	(g)	(h)	713
Weight for a mass of 100 kg	200 km	(i)	7.0 min	(j)

33.2 A builder needs to drag a sack of cement 20 m along the floor against a friction force of 60 N.

(a) Calculate the work done needed.

(b) The dragging took two minutes. What was power of the builder?

33.3 How much gravitational potential energy is lost when a 60 kg boy walks down a flight of stairs which is 4.5 m high?

33.4 A weight-lifter raises a barbell of mass 20 kg, doing 490 J of work on it. Through what height does she lift the barbell?

33.5 A lighting bar on stage has a mass of 300 kg when supporting stage lights.

(a) What is its weight?

(b) How much energy do you need to lift it by 10 m?

(c) If your power is 100 W, how long would it take you to lift the bar by 10 m?

(d) What is the increase in gravitational potential energy when the bar is lifted by 10 m?

33.6 A car park has three floors. The ground floor is at street level. The first floor is 4.0 m above the ground floor, the second floor is 3.0 m above the first floor.

(a) How much energy does it take to lift an 800 kg hatchback to the top level from the street?

(b) How much energy does it take to lift a 2000 kg SUV to the first floor from the street?

(c) Calculate the change in gravitational potential energy when a 400 kg city car moves to the top floor.

(d) ♡ Calculate the change in gravitational potential (that is, the gravitational potential energy per kilogram) in cases (a), (b) and (c) of this question.

33.7 When an object falls in a gravitational field it loses gravitational potential energy.

(a) How much gravitational potential energy is lost when a rock of mass 3.0 kg falls to the foot of a 250 m cliff on the Moon where 'g' is 1.6 N/kg?

(b) In a hydroelectric power station, how much potential energy is lost by 100 tonnes of water flowing down through the pipes, falling a vertical distance of 200 metres? (1 tonne $= 1\,000$ kg)

33.8 A rower exercises with an output power of 200 W. Her boat (containing 7 other equally-strong rowers) travels at a speed of 9.0 m/s.

(a) How far will the boat go in 20 s?

(b) How much energy will the crew have converted in 20 s?

(c) Calculate the force each rower exerts to push the boat along.

(d) What happens if you multiply the force in (c) by the speed of the boat?

Q33.8(d) should show you that there is another useful equation:

$$\text{power} = \text{force parallel to motion} \times \text{speed}$$

$$P = Fv$$

33.9 ♡ A car is being driven down a drag race track.

(a) Calculate the power of car engine needed if the car is to be driven at a constant 70 mph (31 m/s) against a combined friction and air resistance force of 1400 N.

(b) Calculate the power of car engine required to drive the car at a speed of 100 mph (44.7 m/s) against 1400 N of resistive force.

(c) In practice, the car needs a much more powerful engine. Why?

33.10 A mountain climber has a mass (with all of their equipment) of 95.0 kg. If they were perfectly efficient, and ate 500 g of chocolate (11.1 MJ of chemical energy), how high could they climb?