Chapter 5

Work, Energy and Power

"There is a fact, or if you wish, a law governing all natural phenomena that are known to date. There is no known exception to this law – it is exact so far as we know. The law is called the conservation of energy.

It states that there is a certain quantity, which we call "energy," that does not change in the manifold changes that nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says there is a numerical quantity which does not change when something happens.

It is not a description of a mechanism, or anything concrete; it is a strange fact that when we calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same.

It is important to realize that in physics today, we have no knowledge of what energy "is." We do not have a picture that energy comes in little blobs of a definite amount. It is not that way. It is an abstract thing in that it does not tell us the mechanism or the reason for the various formulas."

Richard Feynmann
The Feynman Lectures on Physics (Volume 1)

5 Work, Energy and Power

Content

- Work
- Energy conversion and conservation
- Potential energy and kinetic energy
- Power

Learning Outcomes :

(a) show an understanding of the concept of work in terms of the product of force and displacement in the direction of the force.

(b) calculate the work done in a number of situations including the work done by a gas which is expanding against a constant external pressure: $W = p\Delta V$ (to be covered in Chapter 11Thermal Physics)

(c) give examples of energy in different forms, its conversion and conservation, and apply the principle of energy conservation to simple examples.

(d) derive, from the equations of motion, the formula $E_k = ½mv^2$.

(e) recall and apply the formula $E_k = ½mv^2$.

(f) distinguish between gravitational potential energy, electric potential energy and elastic potential energy.

(g) show an understanding of and use the relationship between force and potential energy in a uniform field to solve problems (in Appendix to be covered in later chapters)

(h) derive, from the defining equation $W = Fs$, the formula $E_p = mgh$ for potential energy changes near the Earth's surface.

(i) recall and use the formula $E_p = mgh$ for potential energy changes near the Earth's surface.

(j) show an appreciation for the implications of energy losses in practical devices and use the concept of efficiency to solve problems.

(k) define power as work done per unit time and derive power as the product of force and velocity.

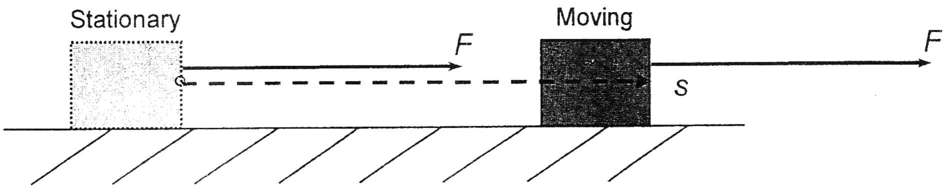
5.1 Work

The meaning of 'work' in physics differs from everyday usage. In Physics, it has a specific meaning that is clearly defined. It describes an effect that occurs when a force interacts with a body that undergoes displacement. It is about the transfer and transformation of energy between one body and another.

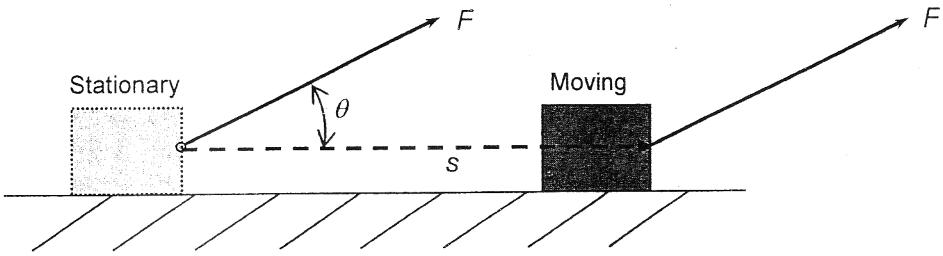
A person holding a heavy book *at rest* may say that he is doing hard work (in the physiological and psychological sense) but he is doing no work at all in the eyes of a physicist. There is no contradiction here. The physicists refer to the work done by a force that is exerted by the person on the book. The physicist is concerned strictly with' the cause' (a particular force) and its effect (work done) on a particular body.

5.1.1 Work done by a constant force

When a force acts through a distance, we say "the force does work". In the simplest case, consider a constant force F acting on a body which undergoes displacement s in the direction of the force.



The work done by the force on the body is defined as the **product of the magnitude of the force F and the displacement s in the direction of the force.**



For the general case when the displacement is not in the direction of the constant force, we can also determine the work done by the force as the product of the displacement and the component of the force in the direction of the displacement. As can be seen below, both lead to the same mathematical expression.

$$W = F\, s_{//} = F\,(s \cos\theta)$$

Alternatively $$W = F_{//}\, s = (F \cos\theta)\, s$$

where F is the magnitude of constant force
s is the displacement
θ is the angle between the force and displacement

Notes:

- Work is a **scalar** quantity. The unit of work is the **joule** (J).
- The force F acts on *a particular point* on the object. The displacement in this expression refers to the displacement of *this point* alone. This point is sometimes called the point of application of the force.
- It is assumed that the object is *not rotating*, or *changing shape* (i.e. it is rigid), so all parts of the object move with the same displacement. The physics of rotating or non-rigid bodies are beyond the A-level syllabus.
- Where there are more than one force acting on a body, work done by the individual forces can be calculated separately.

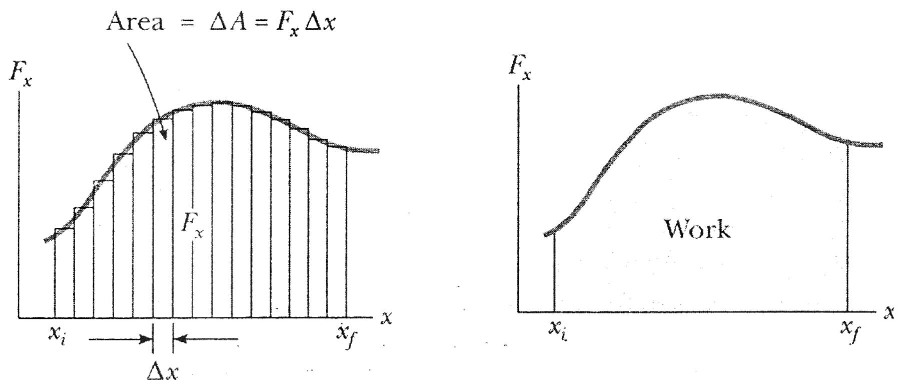
Concept Check 1
(a) When a man is standing and holding a heavy load, is he doing mechanical work on the load? Explain.
(b) As the man is walking around at a constant speed and holding up the load, is any mechanical work being done on the load? Explain why.

Concept Check 2:
Under what circumstance is the work done by a force negative?

Worked Example 1:
A lawn mower is pushed by a force P of 20.0 N at 30° to the horizontal, against a horizontal resistive force D of 8.0 N. It moves a horizontal distance of 10.0 m. Calculate
(i) the work done by the force P on the lawn mower.
(ii) the work done by the resistive force D.
(iii) the work done by the normal contact force from the ground and the weight of the lawn mower.
(iv) the change in kinetic energy of the mower.

5.1.2 Work done by a variable force

Suppose an object is being displaced along the x-axis under the action of a force F_x that acts in the x direction and varies with position. The object is displaced in the direction of increasing x from $x = x_i$ to $x = x_f$. In order to calculate work done by the variable force F_x, we first need to know how the force applied F_x varied with displacement. Let's imagine we were able to use a force sensor and a data logger to measure this variation and that we were able to get the plot shown below.



The total displacement x can be regarded as the sum of many very small steps Δx. During each small step, the force is practically constant.

The total work done = sum of work done for each step

$$W = \Delta W_1 + \Delta W_2 + \Delta W_3 + \ldots\ldots$$

$$= F_1\Delta x + F_2\Delta x + F_3\Delta x + \ldots\ldots$$

As the width of the small steps, Δx, gets really small, the sum of area of these strips will just be the area under the graph of F_x against x.

$$W = \int_{x_i}^{x_f} F_x \, dx$$

In other words, the work done by a variable force acting on an object that undergoes a displacement is equal to the area under the force–displacement graph.

5.2 Energy

In principle, you can solve problems regarding the motion of an object by applying Newton's three laws of motion using vectorial methods. But some problems aren't as simple as they look. How would you determine the speed of a pinball launched by a compressed spring that applies a varying force? How would you determine the motion of one particular molecule in a volume of gas with billions of molecules in random motion? The simple vectorial method that you have learned earlier does not present easy solution where variable forces are involved or where 3 or more bodies are interacting in a system.

The concept of energy provides an ***alternative method*** for dealing with problems in mechanics. It unifies every area of physics even though it is difficult to define just what energy is. Although it is often convenient to classify energy as being chemical or electrical or thermal etc., there are fundamentally only two types of energy – kinetic energy and potential energy from the view point of mechanic.

A body, which is capable of doing work, is said to possess energy. The amount of energy that a body has is equal to the amount of work that it can do.

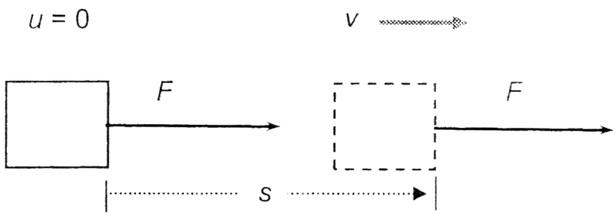
Hence, the energy of a system is a measure of its capacity of to do work.

5.3 Mechanical Energy

The total **mechanical energy** of a system is the sum of all types of **kinetic energy** and **potential energy** of the system.

5.3.1 Kinetic energy (Derivation of $E_k = \frac{1}{2}mv^2$)

Kinetic energy of a body is a measure of the energy possessed by the body **by virtue of its motion.** Suppose an object is being displaced along the x-axis under the action of a constant force,



we can infer the formula for kinetic energy from the amount of work that is done by an external force to bring a body from rest to its state of motion.

$$E_k = F\,s$$

By Newton's second law: $E_k = (ma)s$

Using the equations of motion for uniform acceleration:

$$\begin{aligned} E_k &= ma\left(ut + \tfrac{1}{2}at^2\right) \\ &= ma\left(\tfrac{1}{2}at^2\right) \\ E_k &= \tfrac{1}{2}ma^2t^2 \\ &= \tfrac{1}{2}m\left(\frac{v-u}{t}\right)^2 t^2 \\ &= \tfrac{1}{2}m\left(\frac{v-0}{t}\right)^2 t^2 \\ &= \tfrac{1}{2}mv^2 \end{aligned}$$

Worked Example 2:

In the earlier derivation of $E_k = \frac{1}{2}mv^2$, we conveniently assumed the body was initially at rest. Can you show that in general, work done by a constant force is the gain in kinetic energy of the body?

5.3.2 Potential energy

An object can have energy by virtue of its position or the arrangement of the system that it is part of. The potential energy of a system represents a form of stored energy, which can be fully recovered and converted into kinetic energy.

Potential energy of a body can be defined as the amount of work that was done on it to give it that position.

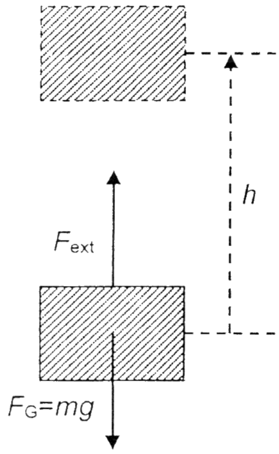
There are three kinds of potential energy. They are summarized in the table below.

Elastic PE	Gravitational PE	Electrical PE
Interaction between charges on atoms and molecules	Interaction between masses	Interaction between charges
Involves attractive and repulsive forces	Involves only attractive forces	Involves attractive and repulsive forces

5.4 Gravitational Potential Energy

To move objects around near the surface of the earth we need to use forces to overcome the Earth's attraction. The work done by exerting forces to overcome this attraction and place objects in positions further and further from the surface of the earth manifests itself as an increasing gravitational potential energy associated with that object.

The **gravitational potential energy** (G.P.E) of a body is a measure of the energy it possesses by **virtue of its position in a gravitational field.**



We can infer the formula for G.P.E. from the amount of work that is done by an external force F_{ext} to lift a body through a vertical distance of h at constant speed.

$$W = F_{ext}s$$

To just overcome the gravitational pull, $F_{ext} = mg$.

$$W = (mg)(h) = mgh$$

Hence, gain in G.P.E $= mgh$

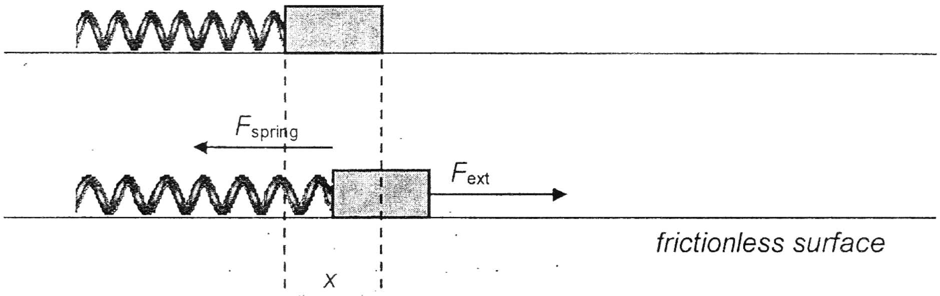
Note:
This derivation applies only to objects that stay near to the surface of the Earth during the motion, and h is small relative to the diameter of the Earth so that the gravitational pull on the body (i.e. its weight mg) is practically constant during the motion.

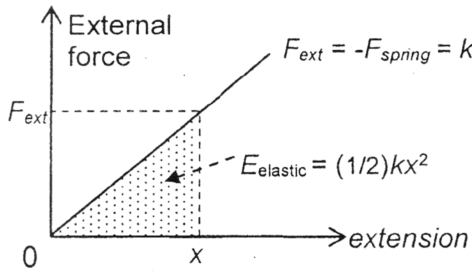
Worked Example 3
A mass of weight 5.0 N is lifted by a vertical force of 7.0 N through a vertical distance of 2.0 m.
a) Calculate the work done by the lifting force.
b) Calculate the change in Gravitational Potential Energy, assuming it was initially at rest.
c) Calculate the final speed of the mass.

5.5 Elastic Potential Energy

Forces need to be exerted to alter the shape (length) of a spring. Hence for each particular extension of the spring, there is an associated elastic potential energy value. For any particular displacement, this depends on the stiffness of the spring. A stiffer spring requires larger forces to deform it so that you will end up having done more work to attain a particular extension and hence will have a larger elastic potential energy associated with that extension.

The external force which is required to change the position of an object near the earth's surface is always equal to the weight of the object and hence constant. Changing the length of a spring, however, requires an external force that increases in proportion to the extension.





Let a light spring be stretched through an extension x, very slowly (at practically zero velocity) by applying an external force F_{ext}.

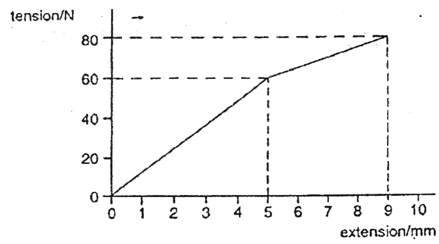
If the spring obeys Hooke's law, the spring force F_{spring} is proportional to its extension x, i.e. $F = -kx$, where k is the spring constant. To just overcome the spring force, the external force $F_{ext} = - F_{spring}$.

$$
\begin{aligned}
W &= \text{area under the } \textit{force–extension graph} \\
&= \tfrac{1}{2} F x \\
&= \tfrac{1}{2} (k x)(x) \\
E_{elastic} &= \tfrac{1}{2} kx^2
\end{aligned}
$$

Hence, elastic potential energy $E_{elastic} = \frac{1}{2}Fx = \frac{1}{2}kx^2$

Worked Example 4 (J99/I/23)

A sample is placed in a tensile testing machine. It is extended by known amounts and the tension is measured. What is the work done on the sample when it is given a total extension of 9.0 mm?



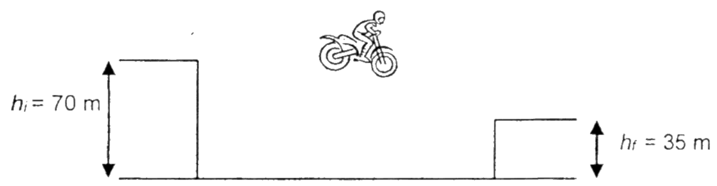
5.6 Principle of Conservation of Energy

The importance of the energy idea stems from the principle of conservation of energy:

Energy can be **converted from one form to another** but **cannot be created or destroyed**.

Worked Example 5

A motorcyclist leaps across a canyon by driving horizontally off a cliff at a speed of 38.0 m s^{-1}. Ignoring air resistance, find the speed with which the cycle strikes the ground on the other side.

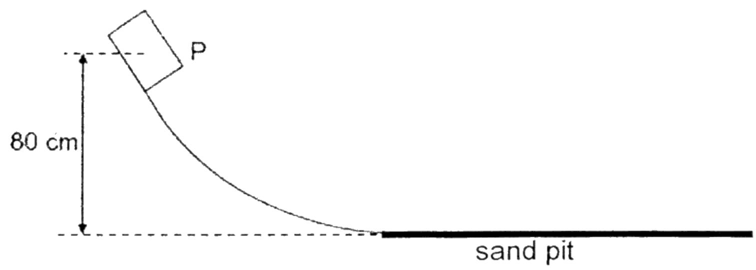


Worked Example 6:

A car of mass 800 kg moving at 30 km h^{-1} along a horizontal road is brought to rest by a constant retarding force of 5000 N. Calculate the distance the car moves before coming to rest.

Worked Example 7

A block of mass 4.0 kg is released at point P on a curved frictionless track as shown. The block slides down a vertical distance of 80 cm and enters a sand pit. Determine the distance the block can move along the sand pit before coming to rest if the friction acting on the block is 85 N.



5.7 Power

The same amount of work is done in raising a given body through a given height, regardless whether it takes one second or one year to do so. However, *the rate at which work is done* is greater for the former than that for the latter.

Power is defined as the rate at which work is done.

$$\text{Instantaneous power, } P = \frac{dW}{dt}$$

$$\text{Average power, } \langle P \rangle = \frac{\Delta W}{\Delta t}$$

Notes:

- The SI unit of power is the **watt** (W). Power is a **scalar** quantity.
- Work can also be expressed in units of (power x time). This is the origin of the term *kilowatt-hour.* One *kilo-watt hour* is the work done in 1 hour by an agent working at a constant rate of 1 kW.

Worked Example 8

A 1.10×10^3 kg car, starting from rest, accelerates for 5.00 s. The magnitude of the acceleration is $a = 4.60$ m s^{-2}. Determine the average power generated by the net force that accelerates the vehicle.

5.7.1 Relationship between Power, Force and Velocity

Consider a force F that acts on a body for a small time interval Δt. The body moves a small displacement Δx in the direction of the force.

Work done by the force F during Δt, $\quad \Delta W = F\,\Delta x$

Power delivered by that force F during the time interval Δt

$$\begin{aligned} P &= \Delta W / \Delta t \\ &= (F\,\Delta x) / \Delta t \\ &= F(\Delta x / \Delta t) \\ &= Fv \end{aligned}$$

where v is the instantaneous velocity of the body.

When a force F acts on a body that is moving with velocity v, in the direction of the force, it delivers power to the body at the rate given by $P = Fv$

Notes:

- A force F that acts in the direction of the displacement Δx, does positive work on the body. It transfers energy to the body at a rate proportional to the speed of the body.
- If F or v varies with time, then P may not be constant. However, the product Fv at any moment will gives the instantaneous power of F at that instant.
- Where F acts against the motion of the body, it does negative work on the body. It extracts energy out of the body at a rate equal to the magnitude of Fv.

Worked Example 9:
A car is moving with a constant velocity of 20.0 m s^{-1} along a straight horizontal road. The total resistive forces acting on the car is 2000 N. What is the power developed by the engine of the car?

5.8.2 Efficiency (of energy conversion), η

No practical engine can transform energy from one form to another without some energy going to internal energy and other non-useful forms of energy.

The efficiency of any energy conversion process is the ratio of

- the useful energy output to the total energy input, or
- the useful power output to the power input

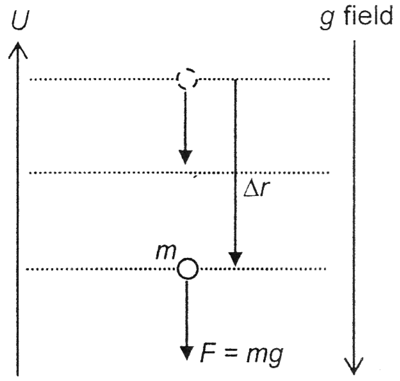
$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \quad , \quad \eta = \frac{E_{output}}{E_{input}} = \frac{P_{output}}{P_{input}}$$

Note:
η is a ratio between two quantities of the same type. It has no unit.

Worked Example 10:
A small motor is used to raise a weight of 2.0 N at constant speed through a vertical height of 80 cm in 4.0 s. The efficiency of the motor is 20 %. What is the electrical power supplied to the motor?

Appendix 1:
Relationship between field force and potential energy (to be taught in later chapters)

We have seen that in general, potential energy is a function of position such that the difference between its value at an initial and final position is always equal to the work done in moving an object between these positions. We will use this concept to arrive at a general rule for the relationship between a potential energy function (how the potential energy varies with displacement) and the size of the force generated by the field. We shall for simplicity's sake consider a uniform gravitational field.



Consider a mass that falls freely under the pull of gravity F, through a vertical distance Δr in the direction of F.

Work done by the gravitational force, $W = F\,\Delta r$

Work done = Difference in Potential Energy = $-\Delta U$ (Decrease in P.E.)

$$\therefore F\,\Delta r = -\Delta U \qquad \Rightarrow F = -\frac{\Delta U}{\Delta r}$$

This concept can be generalised for any conservative field in which energy is not lost. A force is conservative if the work it does on an object moving between two points is independent of the path taken between the points. Examples of conservative forces are gravitational force, electrostatic force and force of a spring.

Conservative fields can have a potential energy function associated with it. Work done in bringing an object from one point to another is simply the difference in the potential energy between those two points.

In any conservative and uniform field, the force exerted by the field is related to the potential energy U of the system by

$$F = -\frac{\Delta U}{\Delta r}$$

The magnitude of the field force at a point in the field is given by the potential energy gradient at that point.

The direction of the field force is in the direction of decreasing potential energy.

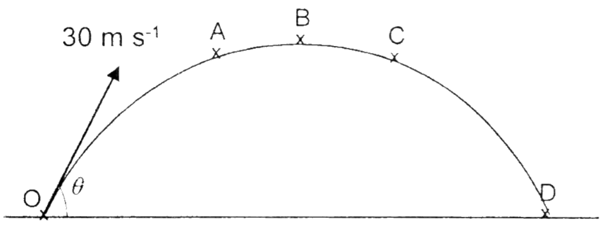
In general, the concept can be generalised to include non-uniform fields:

$$F = -\frac{dU}{dr}$$

Tutorial 5 Work Energy Power

Self-Practice Questions

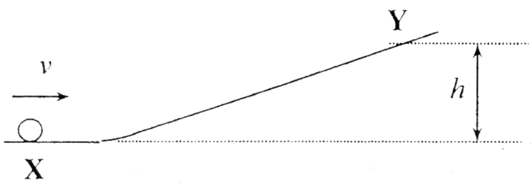
S1 On a horizontal plane, a 2.0 kg particle is fired from point O at an angle of 60° above the horizontal with an initial speed of 30 m s^{-1}. When the particle is at point B, it is at its maximum height from the ground. Assuming that the effect of air resistance is negligible, at which point on the particle's trajectory is its kinetic energy minimum?



S2 (J77/2/30) 500 kJ of heat was produced when a vehicle of total mass 1600 kg was brought to a rest on a level road. The speed of the vehicle just before the brakes were applied was

A 0.625 m s^{-1} **B** 0.79 m s^{-1} **C** 25 m s^{-1} **D** 62.5 m s^{-1} **E** 625 m s^{-1}

S3 (J87/1/5) An object of mass m passes a point **X** with a velocity v and slides up a frictionless incline. It stops at a point **Y** which is at a height h above the point **X**.



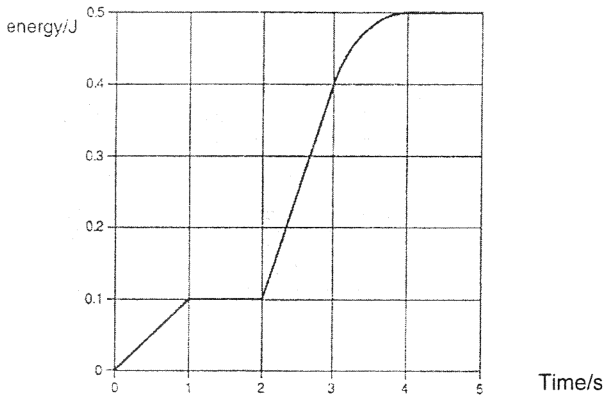
A second object of mass 0.5 m passes the point **X** with a velocity of $0.5v$. To what height will it rise?

A $0.25\,h$ **B** $0.5\,h$ **C** $(1/\sqrt{2})\,h$ **D** h **E** $h\sqrt{2}$

S4 (J87/1/8) An electric motor is required to haul a cage of mass 400 kg up a mine shaft through a vertical height of 1200 m in 2.0 minutes. What will be the electrical power required if the overall efficiency is 80% ?
[Take g as 10 m s^{-2}.]

A 3.2 kW **B** 5.0 kW **C** 32 kW **D** 50 kW **E** 3000 kW

S5 (J94/1/6) A bicycle dynamo is started at time t = 0 s. The total energy transformed by the dynamo during the first 5 seconds increases as shown in the graph.



What is the maximum power generated at any instant during these first 5 seconds?

A 0.10 W **B** 0.13 W **C** 0.30 W **D** 0.50 W

S6 (J93/1/6) A small metal sphere of mass m is moving through a viscous liquid. When it reaches a constant downward velocity v, which of the following describes how the kinetic energy and gravitational potential energy of the sphere changes with time?

A K.E.: constant and equal to $\frac{1}{2}mv^2$ G.P.E.: decreases at a rate of mgv

B K.E.: constant and equal to $\frac{1}{2}mv^2$ G.P.E.: decreases at a rate of $(mgv - \frac{1}{2}mv^2)$

C K.E.: constant and equal to $\frac{1}{2}mv^2$ G.P.E.: decreases at a rate of $(\frac{1}{2}mv^2 - mgv)$

D K.E.: increases at a rate of mgv G.P.E.: decreases at a rate of mgv

E K.E.: increases at a rate of mgv G.P.E.: decreases at a rate of $(\frac{1}{2}mv^2 - mgv)$

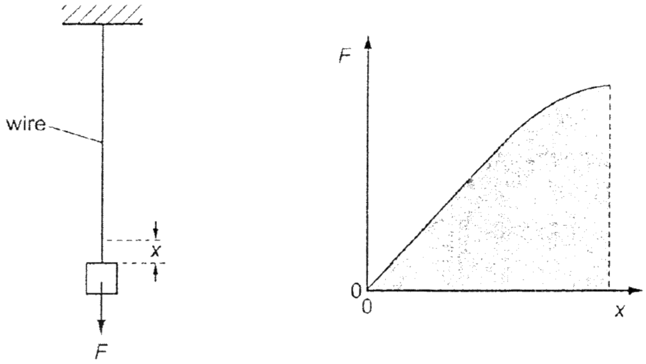
S7 (H1/2012/1/15) A car of mass 1000 kg travels up a hill at constant speed. It gains 87 m in height travelling a distance of 500 m. The total frictional force is 580 N. What is the work done by the driving force?

A 0.85 MJ **B** 1.14 MJ **C** 4.90 MJ **D** 5.19 MJ

S8 (N92/1/6) A body of mass m moves at constant speed v for a distance s against a constant force F. What is the power required to sustain this motion?

A mv **B** (1/2) mv^2 **C** (1/2) Fs **D** Fs **E** Fv

S9 (H1/N2009/1/6) A wire, fixed at its upper end, is subjected to an increasing load F by increasing the mass attached to its lower end. A graph of F against the extension x of the wire is shown.



The wire is stretched beyond its elastic limit. What does the shaded area on the graph represent?

A the amount of elastic potential energy stored in the wire
B the amount of heat produced in the wire
C the loss of gravitational potential energy of the mass
D the work done by F on the wire

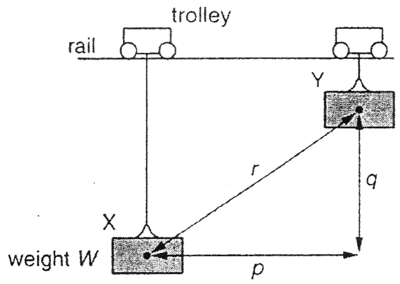
S10 A cart is gliding over an air track at 0.50 m s^{-1} when the air is suddenly turned off so that the cart now comes into contact with the track. The cart comes to rest after travelling 1.00 m. The experiment is repeated, but now the cart is moving at 0.71 m s^{-1} when the air is turned off.

How far does the cart travel before coming to a rest?

A 1.0 m **B** 2.0 m **C** 4.0 m **D** 8.0 m

Discussion Questions

D1 (CIE June 2003) A weight W hangs from a trolley that runs along a rail. The trolley moves horizontally through a distance p and simultaneously raises the weight through height q.



As a result, the weight moves through a distance r from X to Y. It starts and finishes at rest. How much work is done on the weight during this process?

A Wp **B** $W(p+q)$ **C** Wq **D** Wr

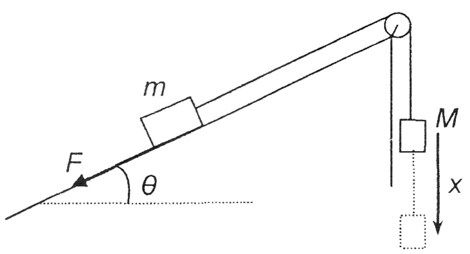
D2 (N2012/1/10, modified) The top end of a spring is attached to a fixed point and a mass of 4.2 kg is attached to its lower end. The mass is released and after bouncing up and down several times it comes to rest at a distance 0.29 m below its starting point. Which row gives the gain in the gravitational potential energy of the mass E_p and the gain in the elastic potential energy of the spring E_s?

	E_p / J	E_s / J
A	−12	+12
B	−12	+6
C	+12	+12
D	+12	+6

D3 (HCJC, Promo 2004) A block of mass 5.0 kg is released from a height of 1.0 m. What is the average power, in W, delivered to the block from release to hitting the ground?

A $\frac{5}{2}g^{3/2}$ **B** $\frac{5\sqrt{2}}{2}g^{5/2}$ **C** $\frac{5\sqrt{2}}{2}g^{3/2}$ **D** $\frac{5}{2}g^{2}$

D4 (J88/1/6) A mass m moves on a rough plane inclined at an angle θ to the horizontal. It experiences a constant frictional force F. Mass M is attached to it by a light inelastic cord running over a smooth pulley. During motion, the mass M is allowed to fall a vertical distance x, causing m to move up the plane as shown in the diagram. How much heat is generated by the friction in this process?



A Fx **B** mgx **C** $Mgx \sin\theta$ **D** $Mgx \sin\theta - Fx$ **E** $Mgx \sin\theta + Fx$

D5 (N88/1/5) What is the power required to give a body of mass m a forward acceleration a when it is moving with velocity v up a frictionless track inclined at an angle θ to the horizontal?

A $mavg\sin\theta$ **B** $mav\sin\theta + mgv$ **C** $mav + mgv\sin\theta$ **D** $(mav + mgv)\sin\theta$ **E** $\dfrac{(mav + mgv)}{\sin\theta}$

D6 (CIE/N2011/1/16, modified) A man of mass m, ties himself to one end of a rope which passes over a single fixed pulley. He pulls on the other end of the rope to lift himself up at an average speed of v. Which of the following expressions gives the average useful power at which he is working?

A $mgv / 2$ **B** mgv **C** $mgv + ½ mv^2$ **D** $mgv - ½ mv^2$

D7 (H1/N2009/1/12) The drag force acting on a car moving at velocity v through still air is proportional to v^2. When the car is travelling at 20 m s^{-1} on a level road, the power required to overcome the drag force is 4800 W. What power is required when the car travels at 25 m s^{-1}?

A 6000 W **B** 7500 W **C** 8000 W **D** 9400 W

D8 (N2009/1/12) A driving force of 200 N is needed for a car of mass 800 kg to travel along a level road at a speed of 20ms^{-1}. What power is required to maintain the car at this speed up a gradient in which the car rises 1 m for each 8 m of travel along the road?

A 6.0 kW **B** 7.2 kW **C** 20 kW **D** 24 kW

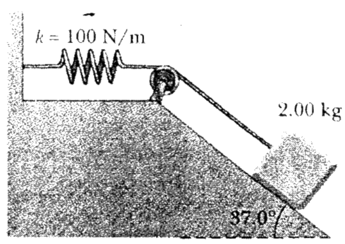
D9 (Physics by Halliday) A helicopter is used to lift a 70 kg astronaut vertically 15 m from the ocean by means of a cable. The acceleration of the astronaut is 0.10 g. Ignore air resistance on the astronaut.

(a) How much work is done by the helicopter on the astronaut?
(b) With what speed does the astronaut reach the helicopter?

D10 (College Physics by Serway & Faughn) A 80.0 kg sky diver jumps out of a balloon at an altitude of 1000 m and opens the parachute at an altitude of 200 m. The total retarding force on the diver is constant at 50.0 N with the parachute closed and constant at 3600 N with the parachute open.

(a) What is the speed of the diver when he lands on the ground?
(b) At what height should the parachute be opened so that the final speed of the sky diver when he hits the ground is 5.00 m s^{-1}?

D11 (College Physics by Serway & Faughn) A 2.00 kg block situated on a rough incline is connected to a spring of negligible mass having a spring constant of 100 N m^{-1}. The block is released from rest when the spring is un-stretched and the pulley is frictionless. The block moves 20.0 cm down the incline before coming to rest. Ignore air resistance.



Find the average resistive force due to friction between the block and the incline.

D12 (H1 2009 P2 Q7) Fig 7.1 shows a man doing a bungee jump. The man has a mass of 75.0 kg and falls a distance of 41.0 m before the elastic rope attached to him starts to exert any force on him.

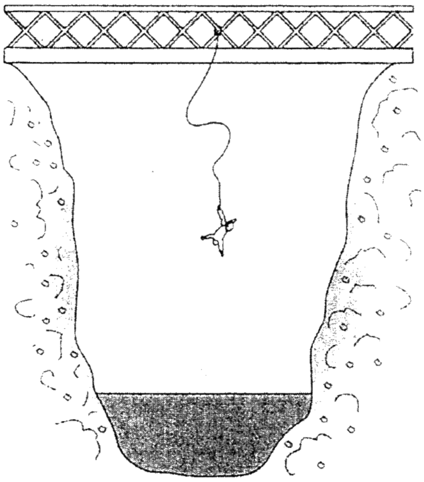


Fig. 7.1

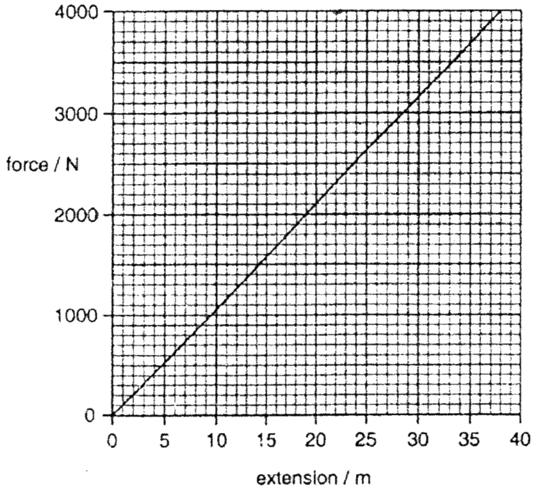


Fig. 7.2

(a) (i) Calculate the theoretical time taken for the fall of this distance. [2]

(ii) The actual time for this fall is 2.9 s. State the deduction you can make by comparing the actual time with your answer to (i). [1]

(b) A force-extension graph for the elastic rope used for the bungee jump is shown in Fig 7.2. The total distance of fall for the man before he stops for the first time is 73.0 m. Deduce

(i) the extension of the rope when the man stops for the first time. [1]

(ii) the elastic potential energy stored in the rope at this time. [2]

(c) (i) Complete the table below to show how the gravitational potential energy and the kinetic energy of the man and the elastic potential energy stored in the rope change with the distance fallen.

	at the top	after falling 41 m	after falling 73 m (i.e. when stopped)
gravitational potential energy / J			0
elastic potential energy / J			
kinetic energy / J			

(ii) Calculate

1. how far the man has fallen from the top when he has maximum kinetic energy [2]

2. the maximum kinetic energy of the man during the fall [3]

(iii) Use your values to sketch three graphs on Figure 7.4 showing how the three different types of energy vary with distance fallen. Label each graph. [4]

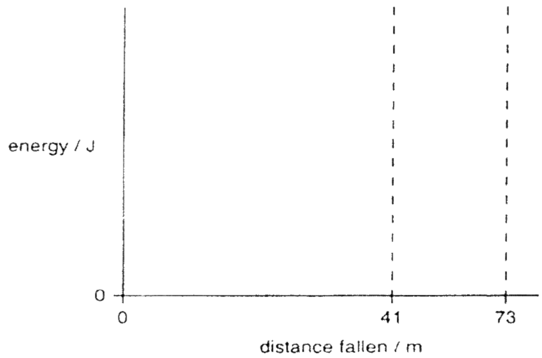


Fig. 7.4

Numerical Answers

S1 B **S2** C **S3** A **S4** D **S5** C **S6** A **S7** B **S8** E **S9** D **S10** B

D9 (a) 1.1×10^4 J (b) 5.4 m s^{-1}
D10 (a) 24.9 m s^{-1} (b) 207 m
D11 1.81 N
D12 (a) (i) 2.89 s (b) (i) 32.0 m (b) (ii) 5.44×10^4 J (c) (ii) (1) 48 m (c)(ii)(2) 3.27×10^4 J