ENERGY AND FIELDS TUTORIAL

Self-Check Questions

S1 Define work done by a force.

S2 Derive, from the equations for uniformly accelerated motion in a straight line, the equation $E_k = \frac{1}{2}mv^2$.

S3 Derive, from the definition of work done by a force, the equation $\Delta E_p = mg\Delta h$ for gravitational potential energy changes near the Earth's surface.

S4 Explain what is meant by efficiency of a practical device and write an equation to show how efficiency can be calculated.

S5 What is gravitational field strength? State an expression for the gravitational field strength.

S6 What is electric field strength? State an expression for the electric field strength.

S7 Define power and derive power in terms of force and velocity in the direction of the force.

Self-Practice Questions

P1 Determine the work done
- **(a)** by a man exerting a 200 N horizontal force to push a 13 kg load 10 m up a slope that is inclined at 30° above the ground.
- **(b)** by Earth as it exerts a 10 000 N force on a satellite orbiting Earth in a circular path.
- **(c)** against gravity when a basketball player of weight 800 N jumps 0.500 m vertically upwards to catch a ball.

P2 A box of mass 20 kg slides down from rest from the top of a slope 4.0 m in height, reaching the bottom with a speed of 2.5 m s^{-1}.

Calculate the thermal energy generated in the process.

P3 Sketch the electric field lines for
- **(a)** two point charges of equal magnitude and same polarity,
- **(b)** two point charges of equal magnitude and opposite polarity.

P4 A crane lifts a load of 8000 N at constant speed through a vertical distance of 20 m in 4.0 s.

Determine the average power during this operation.

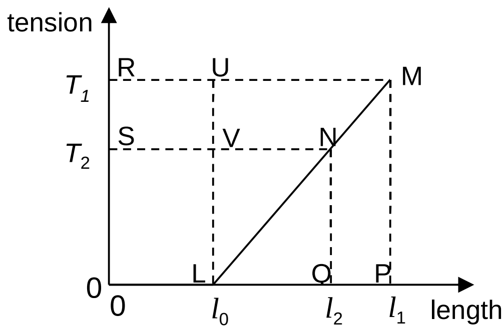
P5 A car travels along a road at a constant speed of 20 m s^{-1}. Its power output is 26 kW. The total frictional force on the car is proportional to the square of its speed.

Determine the power required to travel at a constant speed of 40 m s^{-1}.

Discussion Questions

Energy and Work

1 The given diagram shows the length of a spring increasing from l_0 to l_1 when the tension in the spring is first increased from zero to T_1. The length then decreases to l_2 when the tension is reduced to T_2. Work is done by the spring during the reduction in length. Which area of the graph represents this work done?



2 A bungee jumper of mass 60.0 kg jumps from a bridge. He is tied to a bungee cord of length 12.0 m and falls a total distance of 31.0 m.

(a) Calculate the spring constant k of the bungee cord.

(b) Calculate the maximum acceleration experienced by the jumper.

3 A crate of mass 15.0 kg initially at rest is pushed down a smooth ramp by a constant force of 40.0 N as shown in Fig. 3.1.

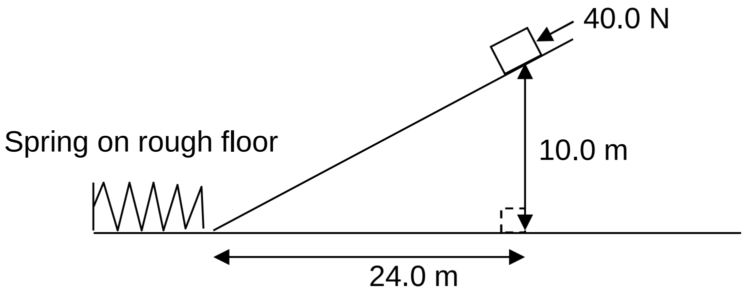


Fig. 3.1

(a) Calculate the speed of the crate at the bottom of the ramp.

(b) At the bottom of the ramp, the force of 40.0 N is removed. The crate is stopped by a spring with a spring constant of 200 N m^{-1}. The frictional force of the floor on the crate is 100 N. Calculate the maximum compression of the spring.

4 A spring that has an unstretched length of 0.650 m is attached to a fixed point. A mass of 0.400 kg is attached to the spring and gently lowered to point X where the mass hangs in equilibrium. The spring has then stretched elastically by a distance of 0.200 m.

(a) Calculate for the stretching of the spring,
(i) the loss in gravitational potential energy of the mass,
(ii) the elastic potential energy gained by the spring.

(b) The load is then pulled to a point 0.200 m below point X. Upon release, the load moves vertically upwards, passes point X and stops momentarily at 0.200 m above point X.

Table 4.1 shows the energy stores of the spring mass system. Complete the Table 4.1.

	gravitational potential energy / J	elastic potential energy / J	kinetic energy / J	total energy / J
0.200m below point X	0			
point X				
0.200m above point X				

Fig. 4.1

5 **(a)** The minimum flying speed for a bird called a house-martin is 9.0 m s^{-1}. It reaches this speed by falling from its nest before swooping away. Calculate the minimum distance its nest must be above the ground.

(b) A house-martin has a mass of 120 g. When it returns to its nest, it is travelling horizontally at P with a speed of 13.0 m s^{-1} and at a distance 7.5 m below its nest. It then glides upwards to the nest, as shown in Fig. 5.1.

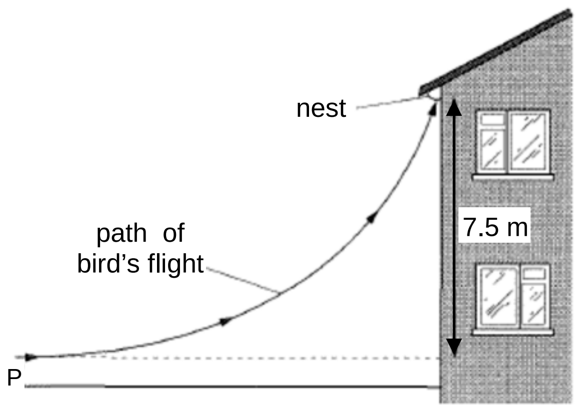


Fig. 5.1

Neglecting any air resistance, calculate

(i) the kinetic energy of the house-martin at P,

(ii) the total gain in potential energy as it glides upwards to its nest,

(iii) its kinetic energy as it reaches its nest,

(iv) its speed as it reaches its nest.

<u>Power and Efficiency</u>

6 A car of mass 1000 kg moves at a constant speed of 20 m s^{-1} along a horizontal road where the frictional force is 200 N.

(a) Calculate the power developed by the engine.

(b) If the car is to travel up an incline with an angle of inclination of 8.0° at the same constant speed, calculate the new power that the engine must develop.

7 A mechanical toy of mass 50.0 kg climbs up a vertical rope for a distance of 8.00 m in 20.0 s.

Calculate

(a) the work done against gravity,

(b) the average power output,

(c) the rate of energy input assuming the toy is 80% efficient.

Field Strengths

8 Point X is 5.0 m away from a point mass of 30 kg as shown in Fig. 8.1.

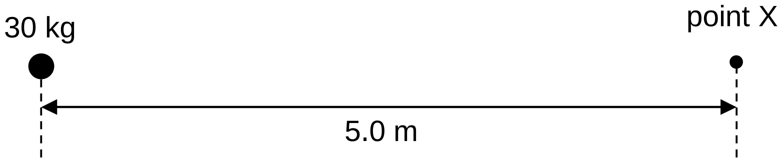


Fig. 8.1

(a) Calculate the magnitude of the gravitational field strength at point X due to the 30 kg mass.

(b) Draw a vector at point X to represent the gravitational field strength in **(a)**.

(c) State the changes in magnitude and direction of the gravitational field strength at point X in comparison with the original gravitational field strength in **(a)**, if

(i) the 30 kg mass is changed to 10 kg mass,

(ii) the point X is 10.0 m away from the 30 kg mass,

(iii) a 10 kg mass is placed at point X.

9 A pair of equal and opposite point charges each of magnitude of 2.0 μC is separated by 1.0 m as shown in Fig. 9.1.

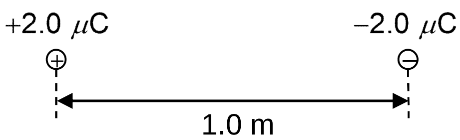


Fig. 9.1

Determine the electric field strength at the midpoint between the two charges.

10 **(a)** Fig. 10.1 shows two equal positive point charges.

Fig. 10.1

On Fig. 10.1, sketch the electric field lines in the region around the two point charges. Mark with a letter N the position where the electric field strength is zero.

(b) Point charges A, of 2.0 nC, and B, of −3.0 nC are placed 200 mm apart in a vacuum, as shown in Fig. 10.2. The point P is 120 mm from A and 160 mm from B.

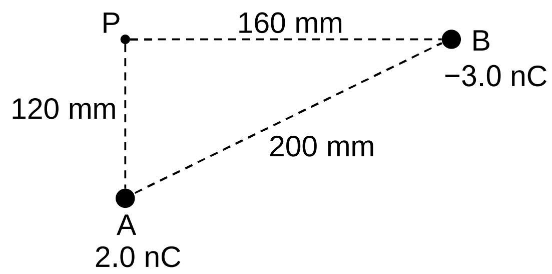


Fig. 10.2

Calculate

(i) the electric field strength at P due to charge A alone,

(ii) the electric field strength at P due to charge B alone,

(iii) the magnitude and direction of the resultant electric field strength at P.

Challenging Question

11 Fig. 11.1 shows a man doing a bungee jump.

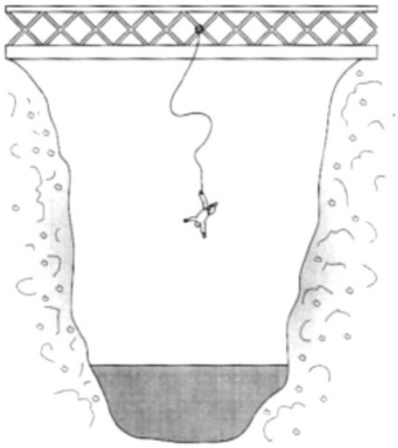


Fig. 11.1

The man has a mass of 75 kg and falls a distance of 41 m before the elastic rope attached to him starts to exert any force on him.

(a) Fig. 11.2 show the force-extension graph for the elastic rope used for the bungee jump.

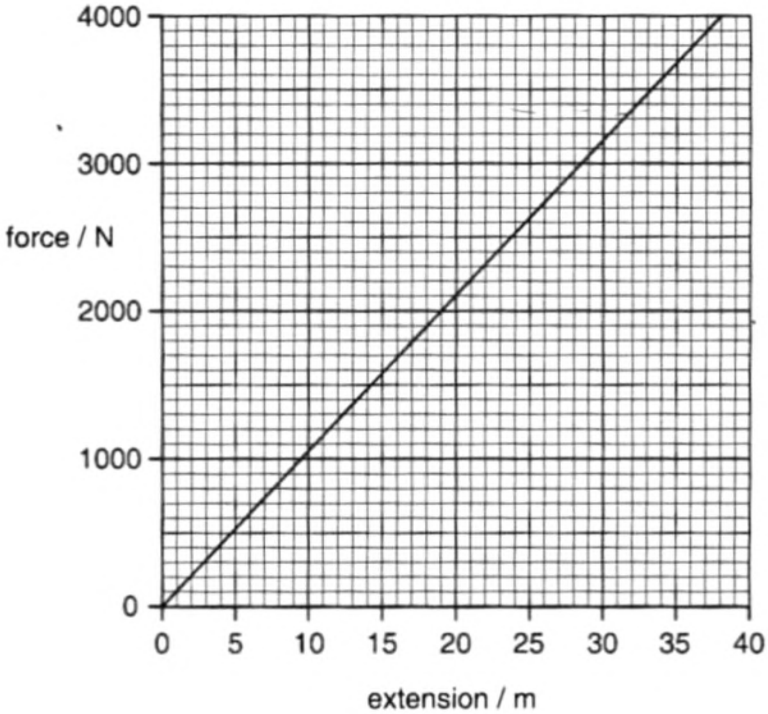


Fig. 11.2

The total distance of fall for the man before he stops for the first time is 73 m.

Deduce

(i) the extension of the rope when the man stops for the first time,

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

(b) (i) Complete Fig. 11.3 to show the gravitational potential energy and the kinetic energy of the man at the three points stated, together with the elastic potential energy stored in the rope. The gravitational energy at the bottom of the fall is taken to be zero.

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

Fig. 11.3

(ii) Calculate

1. how far the man has fallen from the top when he has maximum kinetic energy,

2. the maximum kinetic energy of the man during the fall.

(iii) Use your values to sketch three graphs on Fig. 11.4 showing how the three different types of energy vary with distance fallen. Label each graph clearly.

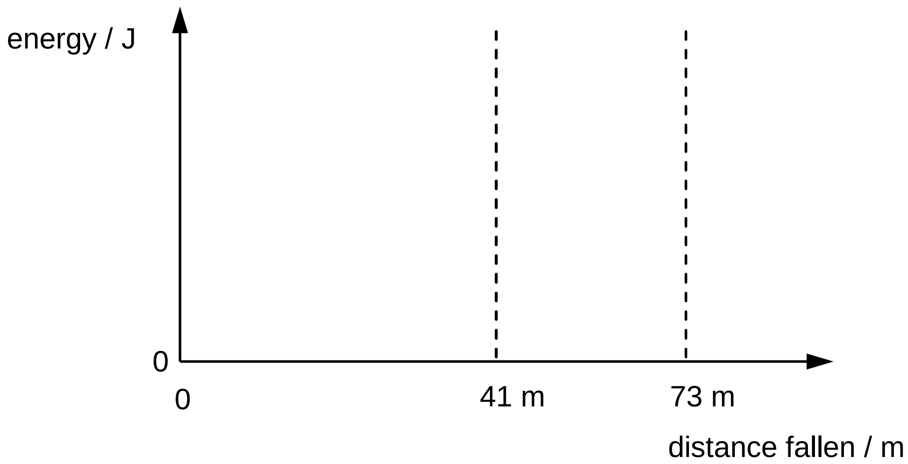


Fig. 11.4

Answers to selected questions:

P1	**(a)** 1700 J **(b)** 0 J **(c)** 400 J	**5**	**(a)** 4.13 m **(b)(i)** 10.1 J **(b)(ii)** 8.83 J **(b)(iii)** 1.27 J **(b)(iv)** 4.60 m s^{-1}
P2.	722 J	**6**	**(a)** 4.0×10^3 W **(b)** 3.1×10^4 W
P4	40 kW	**7**	**(a)** 3.92×10^3 J **(b)** 196 W **(c)** 245 W
P5	208 kW	**8**	**(a)** 8.0×10^{-11} N kg^{-1}
2	**(a)** 101 N m^{-1} **(b)** 22.2 m s^{-2}	**9**	1.44×10^5 N C^{-1} (rightwards)
3	**(a)** 18.3 m s^{-1} **(b)** 4.54 m	**10**	**(b)(i)** 1.25×10^3 N C^{-1} (upwards) **(b)(ii)** 1.05×10^3 N C^{-1} (rightwards) (**b)(iii)** 1.63×10^3 N C^{-1} at 49.8° above horizontal
4	**(a)(i)** 0.785 J **(a)(ii)** 0.392 J	**11**	**(a)(i)** 32 m **(a)(ii)** 5.4×10^4 J **(b)(ii)1.** 48 m **2.** 33000 J