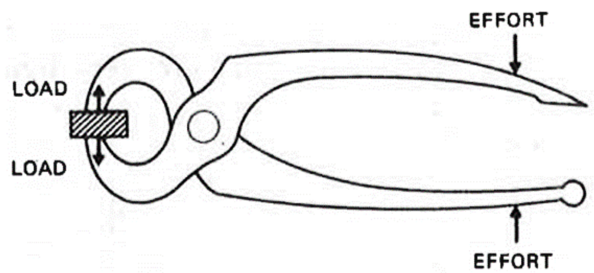
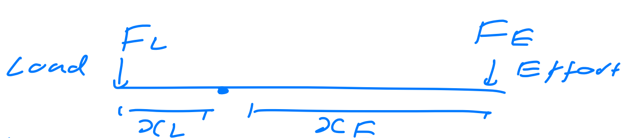
Section A

1. A pair of pliers is a simple machine consisting of two levers. For the pliers shown in the diagram, the mechanical advantage is:

   (a) less than one
   (b) equal to one
   (c) greater than one
   (d) less than 100%
   (e) equal to 100%



- Consider one of the two arms



- Balance torque

$$F_L x_L = F_E x_E$$

$$\Rightarrow \quad \frac{F_L}{F_E} = \frac{x_E}{x_L} > 0 \text{ from the drawing}$$

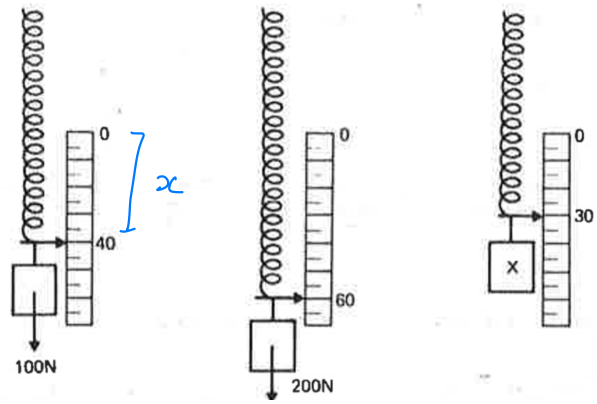
- Mechanical advantage is given by

$$MA = \frac{F_L}{F_E}$$

$$= \frac{x_E}{x_L} > 1$$

$\Rightarrow$ Answer = c.)

The diagrams below show a spring with a pointer attached, hanging next to a scale. Three different weights are hung from it in turn as shown.



2. If all weight is removed from the spring, which mark on the scale will the pointer indicate?

   (a) 0
   (b) 10
   (c) 20
   (d) 25
   (e) 30

- Hooke's Law:

$$F = k(x - L), \quad L = \text{Natural length of Spring}$$

- From the diagrams:

① $100 = k(40 - L)$, ② $200 = k(60 - L)$

②/① $\Rightarrow$ $2 = \dfrac{60 - L}{40 - L}$

$\Rightarrow$ $L = 20$

$\Rightarrow$ Answer = 20

3. What is the weight of X?

   (a) $-10\,\text{N}$
   (b) $0\,\text{N}$
   (c) $30\,\text{N}$
   (d) $50\,\text{N}$
   (e) $75\,\text{N}$

- Using ②: $200 = k(60 - 20) = 40k$

$\Rightarrow k = 5$

- Then by Hooke's Law

$F = kx = 5 \times (30 - 20)$

$= 50N$

$\Rightarrow$ Answer = d.)

4. A person when asleep has a power output of 60 W. In 10 minutes, their food must provide:

   (a) 0.1 J
   (b) 6 J
   (c) 60 J
   (d) 600 J
   (e) 36 000 J

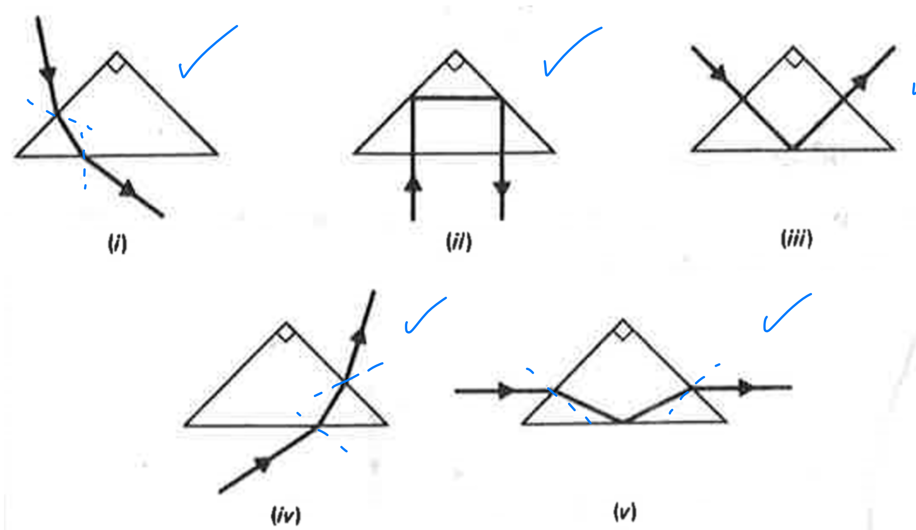
$$\text{Power} = \frac{\text{Energy}}{\text{time}}, \quad P = \frac{E}{t}$$

$$\Rightarrow \quad E = Pt$$

$$\Rightarrow \quad E = 60 \times 10\,\text{min}$$
$$= 60 \times 10 \times 60$$
$$= 36000$$

$\Rightarrow$ Answer = e.)

The following diagrams show a ray of light passing through a glass prism with angles of 45°, 45° and 90°.



5. The correct diagrams are:

   (a) (i) and (iv) only
   (b) (ii) and (iii) only
   (c) (i), (iv) and (v) only
   (d) (i), (ii), (iii) and (iv) only
   (e) All of them

– $n_{prism} > n_{air}$

– So the light will bend towards the normal as it enters prism and away from it as it leaves

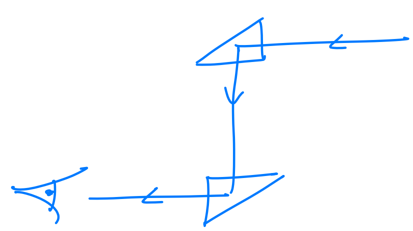
– If light travels along the normal it will not refract

– Use the above facts and process of elimination to get the final solution.

6. Which diagram shows a prism used as in a periscope?

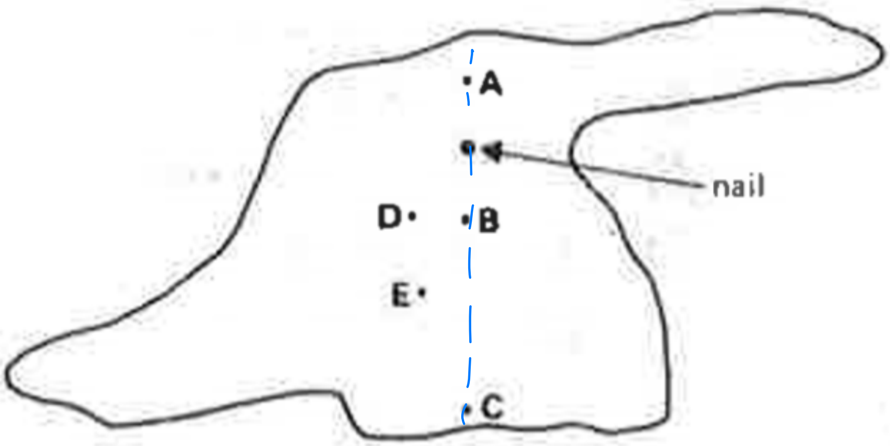
   (a) (i)
   (b) (ii)
   (c) (iii)
   (d) (iv)
   (e) (v)

– An example of a periscope is



(which uses diagram iii)

7. The diagram shows a piece of cardboard hanging freely from a nail. Which point is most likely to indicate the centre of gravity (centre of mass) of the cardboard?



(a) A
(b) B
(c) C
(d) D
(e) E

— If COM was at D or E, we would have a torque around the nail. Then the object wouldn't be steady. So D and E can be eliminated

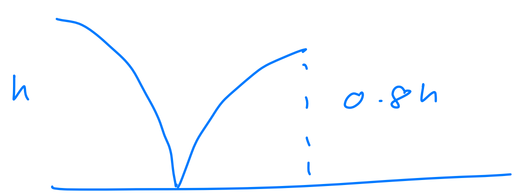
— COM = where most of the mass is located, so C is unlikely

— If the COM was at A, the equilibrium would be unstable (a gentle push would destabalize the cardboard)

— So solution is B

8. A steel ball bearing is dropped onto a concrete floor and rebounds to 80% of its initial height. The percentage of kinetic energy lost in the collision is:

(a) 80%
(b) 64%
(c) 36%
(d) 20%



- Let m = mass of ball
- potential energy = $E_p = mgh$
- By conservation of energy, kinetic energy just before and just after bounce is:

$$E_{k,\text{initial}} = mgh$$

$$E_{k,\text{final}} = 0.8mgh$$

$$\Rightarrow \frac{E_{k,\text{final}}}{E_{k,\text{initial}}} = \frac{0.8mgh}{mgh} = 0.8$$

$\Rightarrow$ 20% of K.E lost in the collision

- Let L = distance between Earth and Moon
- If the Earth takes 24 hours to rotate 360°, in 2 min it rotates

$$360^\circ \times \frac{2\,\text{min}}{24\,\text{hours}}$$

$$= 360^\circ \times \frac{2}{60 \times 24}$$

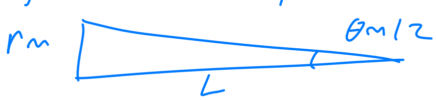
9. The Moon takes 2 minutes to sink below the horizon at the equator when observed at night (about the same time as the Sun takes to set). If the radius of the Earth is 6400 km and the radius of the Moon is 1700 km, what is the angular size of the Earth when observed from the Moon?

r_E $\qquad$ r_m

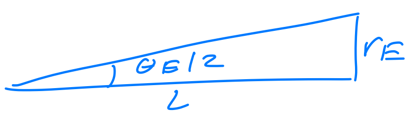
   (a) 3.8°
   (b) 3.5°
   (c) 1.9°
   (d) 0.3°

$$= 0.5^\circ$$

- This is the angular size of the moon when observed from the Earth. To find the angular size of the Earth, on the moon, we use trigonometry



$$\Rightarrow \quad \frac{r_m}{L} = \tan\left(\frac{\theta_m}{2}\right) \approx \frac{\theta_m}{2} \quad (1)$$



$$\Rightarrow \quad \frac{r_E}{L} = \tan\left(\frac{\theta_E}{2}\right) \approx \frac{\theta_E}{2} \quad (2)$$

$$(2)/(1) \quad \Rightarrow \quad \theta_E = \frac{r_E}{r_m}\theta_m = \frac{6400}{1700} \times 0.5 = 1.9^\circ$$

10. Which are the correct dimensions of energy in terms of mass [M], length [L] and time [T]?

   (a) $\frac{MT^2}{L}$
   (b) $\frac{ML}{T^2}$
   (c) $\frac{ML^2}{T^2}$
   (d) $\frac{ML^2}{T}$

- All types of energy has the same dimensions, so consider kinetic energy formula:

$$E = \frac{1}{2} m v^2$$

$$\Rightarrow [E] = [m][v]^2$$

$$= M(LT^{-1})^2$$

$$= \frac{ML^2}{T^2}$$

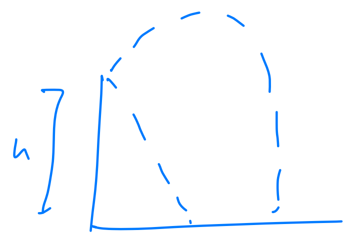
11. Jack and Jill decide to throw pennies out of a window. They lean out and Jill throws hers straight down to the ground with an initial speed of $4\,\mathrm{ms}^{-1}$ whilst Jack throws his straight upwards with an initial speed of $4\,\mathrm{ms}^{-1}$. How do the speeds and kinetic energies of the pennies compare when they each hit the ground? You should ignore air resistance.

   (a) Jack's penny has a greater speed and greater KE

   (b) Jack's penny has the same speed but greater KE

   (c) Jill's penny has the same speed but greater KE

   (d) Jill's penny has the same speed and same KE



- Initial energy of a penny

$$E = \frac{1}{2}mv^2 + mgh$$

- As both pennies are lanched with the same speed, they must have the same initial energies
- No air resistance, so both pennies will always have equal total energies
- When a pennies reach the grand they don't have any potential energy, just kinetic
- So as their total energies are always equal

$\Rightarrow$ Their final K.E will be equal

- As $E_k = \frac{1}{2}mv^2$ and both pennies have the same mass, their speeds will then also be equal

12. The Earth has a mass of 6.0×10^{24} kg and an orbital velocity of $30\,\mathrm{km\,s^{-1}}$ about the Sun. What is its kinetic energy? $= 30 \times 10^3\ \mathrm{m s^{-1}}$

(a) 2.7×10^{27} J

(b) 9.0×10^{28} J

(c) 2.7×10^{33} J

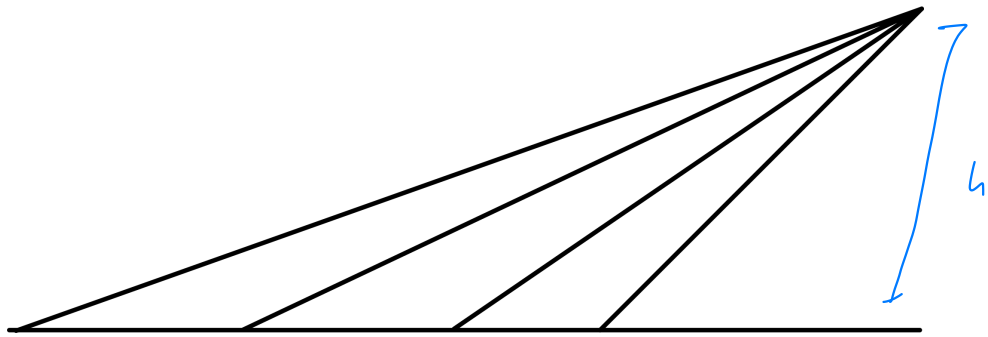
(d) 5.4×10^{33} J

$$E_k = \frac{1}{2} m v^2$$

$$= \frac{1}{2} \times 6.0 \times 10^{24} \times (30 \times 10^3)^2$$

$$= 2.7 \times 10^{33}\ \mathrm{J}$$

13. A particle slides from rest without friction down a set of slopes of different gradients as shown below.



For each slope the particle reaches the bottom after:

(a) Taking the same time

(b) Undergoing the same acceleration

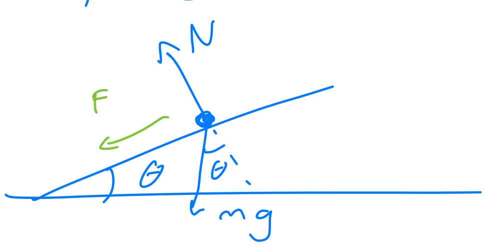
(c) Reaching the same speed

(d) Undergoing the same change of displacement

a.) – Consider the two most extream slopes

– Clearly particle would take longer to go down ①, so answer is not a.)

b.) – Resolve the forces



r ⊥ to slope,

$N = mg\cos\theta$

r ∥ to slope,

$F = mg\sin\theta = ma$

$\Rightarrow a = g\sin\theta$

$\Rightarrow$ different slopes have different accelerations so not a.)

d.) – Not true as particle's end point is different in each case. So not d.)

c.) – Initially particle has energy $E = mgh$

– When it reaches bottom $E = \frac{1}{2}mv^2$

– By conservation of energy

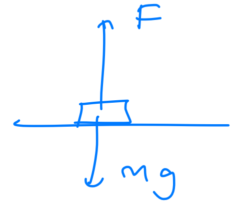
$$mgh = \frac{1}{2}mv^2$$

$\Rightarrow$ Speed only depends on h

$\Rightarrow$ It is the same for each slope

14. A mass m is lifted at a constant slow speed. The force of gravity when it is held in your hand is mg. When it is being lifted the force required is

(a) Slightly less than mg
(b) Equal to mg
(c) Slightly more than mg
(d) Dependent on how fast it is being raised



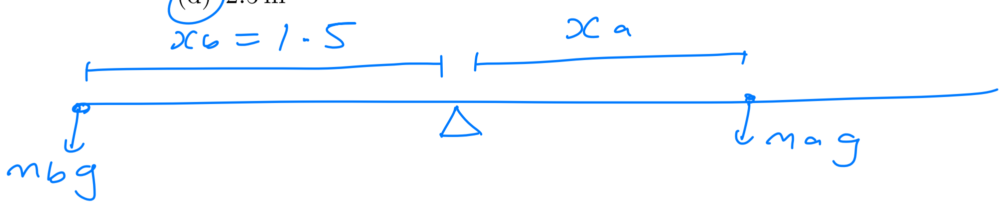
- Mass is raised at constant speed, so by Newton's 2nd Law, all forces must balance

$\Rightarrow$ $F = mg$

$\Rightarrow$ Answer = b.)

15. A symmetric seesaw is 3 m long from end to end. If a boy of mass $\underline{20\,\text{kg}}$ m_b sits on one end, how far away from him should a girl of $\underline{\text{mass } 30\,\text{kg}}$ sit to balance the seesaw? m_a

(a) 0.5 m
(b) 1.0 m
(c) 2.0 m
(d) 2.5 m



- Seesaw is balanced when

$$m_b g x_b = m_a g x_a$$

$$\Rightarrow x_a = \frac{m_b}{m_a} x_b$$

$$= \frac{20}{30} \times 1.5$$

$$= 1$$

$\Rightarrow$ $x_a + x_b = 2.5\,m$

$\Rightarrow$ Answer = d.)

16. A solar eclipse can only occur when the Moon's phase is:

(a) New moon
(b) Full moon
(c) Waning
(d) Waxing

- Solar eclipse

E M S

↳ On Earth moon is dark ⇒ New Moon

17. A 3.6 V mobile phone battery can produce 0.7 A of current for 1 hour. This can be charged using a square solar panel 25 cm on each side. Assuming an efficiency of 10% and an incident solar power of $1\,\text{kW}\,\text{m}^{-2}$, what time is needed to charge the battery?

(a) 0.10 hours
(b) 0.28 hours
(c) 0.40 hours
(d) 1.5 hours

- Energy stored in battery:

$$E = VIt = 3.6 \times 0.7 \times \overbrace{60 \times 60}^{1\,\text{hour}}$$
$$= 9072\,J$$

- Total charging power of panel

$$P = 0.1 \times 1 \times 10^3\,Wm^{-2} \times (\overbrace{25 \times 10^{-2}}^{25\,cm})^2$$
$$= 6.25\,W$$

$$P = \frac{E}{t}$$

$$\Rightarrow t = \frac{E}{P} = \frac{9072}{6.25} = 1451.52\,s$$
$$= 0.4032 \text{ hours}$$
$$= 0.4 \text{ hours}$$

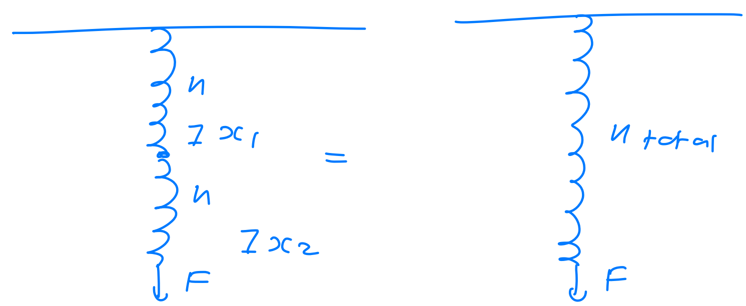
18. Positron Emission Tomography (PET) scanners frequently operate using the radioactive isotope ^{18}F which has a half-life of about two hours. The isotope is incorporated into a drug, half of which is excreted by the body every two hours. How long will it take before the quantity of radioactive drug in the body halves?

    (a) 0.5 hours
    (b) 1 hour
    (c) 1.5 hours
    (d) 2 hours

- So every 2 hours, the quantity of radioactive drug in body will $\times \frac{1}{4}$
- So the quantity will half every 1 hour

19. A spring that obeys Hooke's Law has a spring constant k. Two such springs are linked to form a spring twice the length. What is the spring constant of this new longer spring?

    (a) $\frac{k}{2}$
    (b) $\frac{k}{\sqrt{2}}$
    (c) $\sqrt{2}k$
    (d) $2k$



- Total extension is: $x = x_1 + x_2$ ①
- As the spring is in equilibrium, the force through it is F. So by Hook's Law:

$$F = x_1 k \quad , F = x_2 k \quad , F = x k_{total}$$

- Sub into ①:

$$\Rightarrow \quad \frac{F}{k_{total}} = \frac{F}{k} + \frac{F}{k}$$

$$\Rightarrow \quad \frac{1}{k_{total}} = \frac{2}{k}$$

$$\Rightarrow \quad k_{total} = \frac{k}{2}$$

20. A car accelerates steadily from $0\,\mathrm{ms}^{-1}$ to $20\,\mathrm{ms}^{-1}$ in a distance d and a time t. Another car takes time $2t$ to accelerate steadily from stationary to the same final velocity. What distance does the second car cover during the new acceleration?

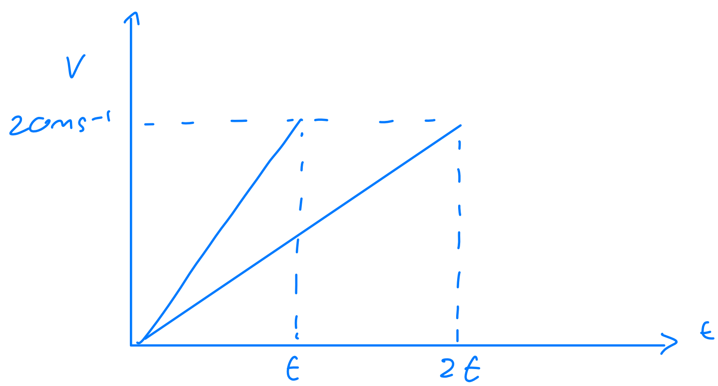
(a) $\frac{d}{4}$

(b) $\frac{d}{2}$

(c) d

(d) $2d$

- Draw a velocity time graph for the two cars:



- Distance travelled = area under graph
- So for the first car:

$$d = \frac{1}{2} \times 20 \times t = 10t$$

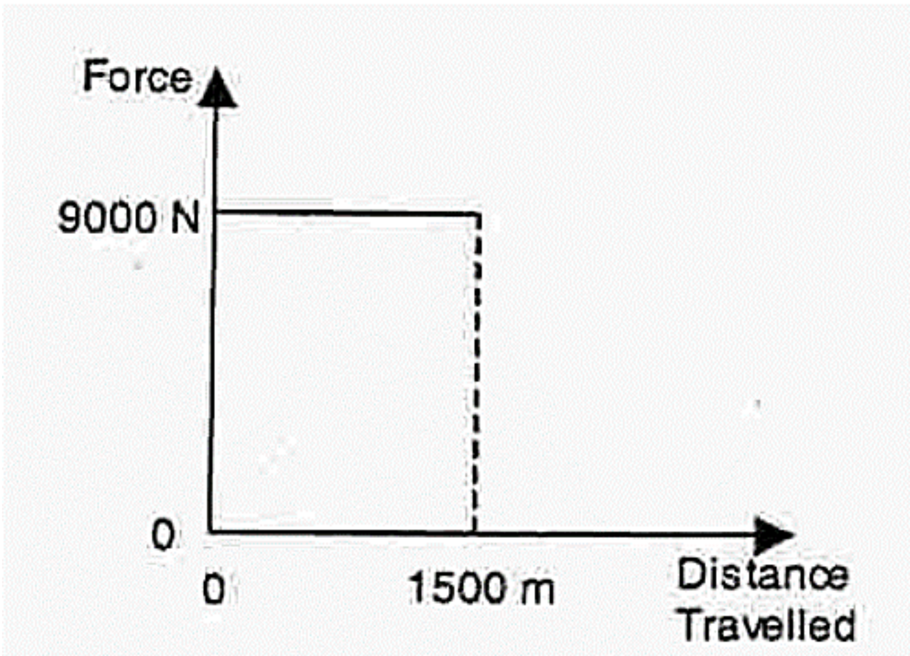
- For the 2nd car

$$\text{distance} = \frac{1}{2} \times 20 \times 2t$$
$$= 20t$$
$$= 2 \times 10t$$
$$= 2d$$

$\Rightarrow$ Answer = d.)

Section B

21. The graph below shows the force on a bus as it accelerates from rest. It reaches full speed after travelling 1500 m. The bus' mass is 30 000 kg. You may assume frictional forces are negligible.



(a) Determine the acceleration of the bus. [1]

$F = ma$

$\Rightarrow a = \frac{F}{m} = \frac{9000}{30000}$

$= 0.3 ms^{-2}$

(b) Find the area under the graph with the correct units. [2]

Area = 9000×1500

$= 13.5 \times 10^6$

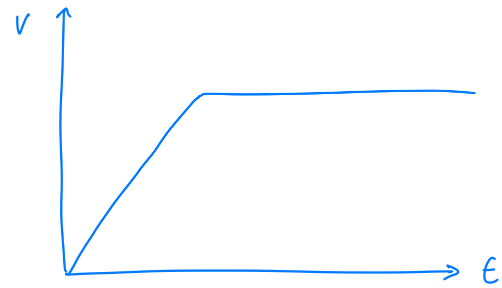
– But area = Force × distance

= Work

– So the units are J

$\Rightarrow$ Area = 13.5 MJ

(c) Sketch a velocity-time graph of this motion. [2]



(d) By finding the final velocity of the bus, comment on its KE. [1]

S	U	V	A	T
1500	0	?	0.3	

$v^2 = u^2 + 2as$

$\Rightarrow \quad v = \sqrt{u^2 + 2as}$

$= \sqrt{2 \times 0.3 \times 1500}$

$= 30\,ms^{-1}$

$E_k = \frac{1}{2} m v^2$

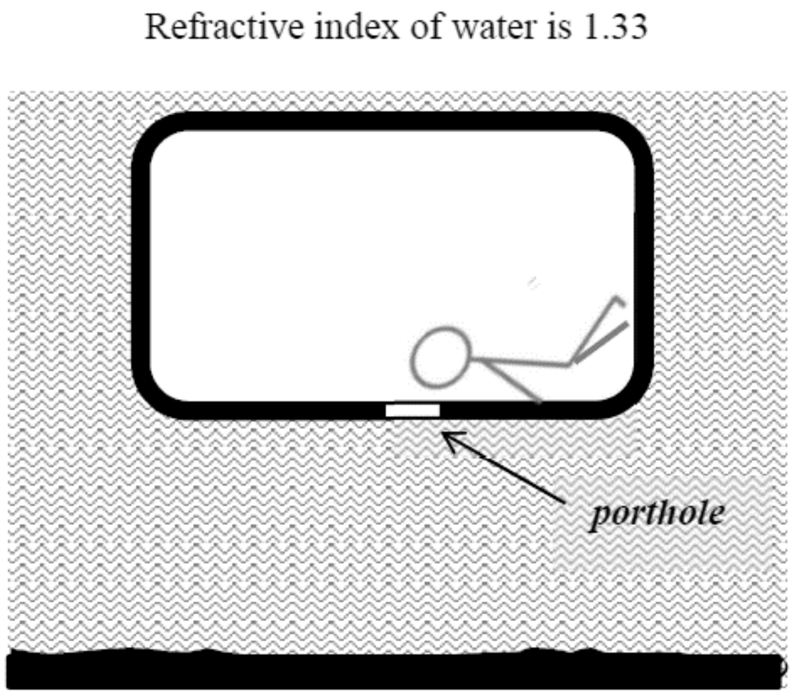
$= \frac{1}{2} \times 30000 \times 30^2$

$= 13.5 \times 10^6\,J$

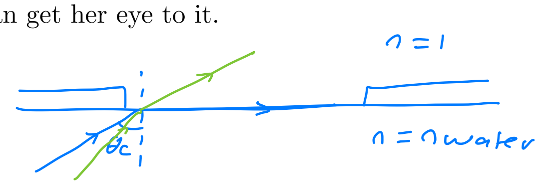
$= 13.5\,MJ$

which is equal to the work done on the bus by the accelerating force, calculated in b.)

22. A diver in a submarine views the seabed through a glass porthole. The diameter of the porthole is 0.20 m and it is set into the bottom of the submarine as shown. The thickness of the glass can be ignored.

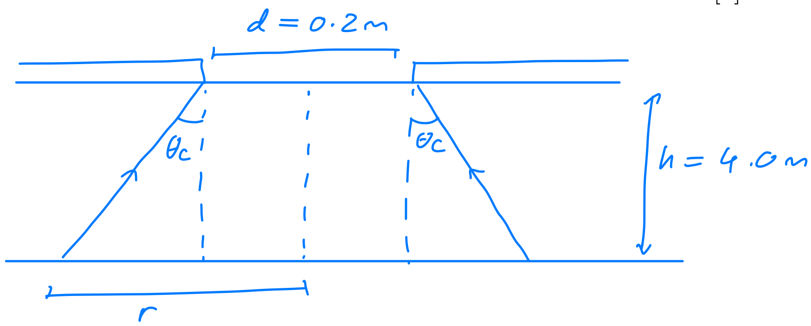


(a) With the aid of a clear diagram, explain why the diver can only view a small area of the seabed through the porthole, no matter how close she can get her eye to it. [2]



- As the refractive index of water is larger than the refractive index of air, light travelling from the sea bed to the submarine can undergo total internal reflection
- So only light from the seabed hitting the porthole with an angle of incidence smaller than the critical angle (θ_c) will reach the diver
- Hence, the diver can only see a small section of the seabed

(b) If the bottom of the submarine is 4.0 m above the seabed, determine the maximum area of seabed which she can view. [4]



- Critical angle satisfies:

$$n_{water} \sin\theta_c = 1$$

$$\Rightarrow \quad \theta_c = \sin^{-1}\left(\frac{1}{n_{water}}\right) = \sin^{-1}\left(\frac{1}{1.33}\right) = 48.8^\circ$$

- Using trigonometry

$$r = h\tan\theta_c + \frac{d}{2}$$

$$= 4 \times \tan(48.8) + 0.1$$

$$= 4.66\,m$$

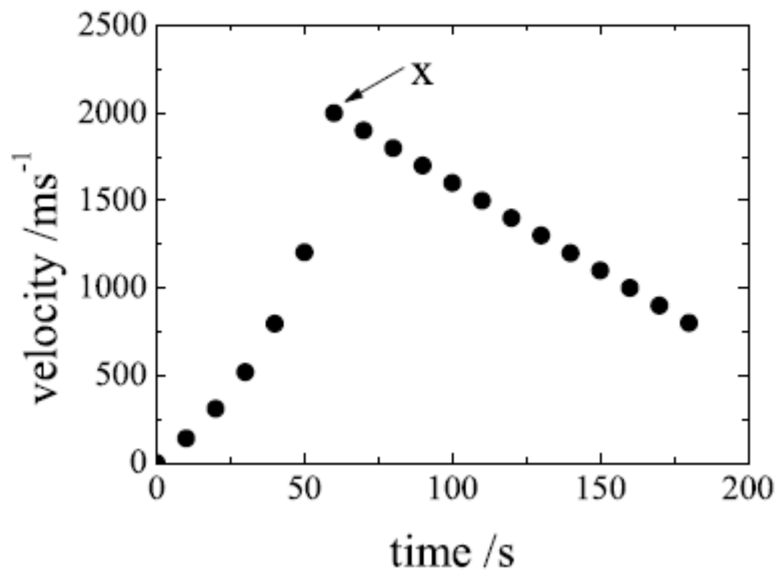
$$\text{Area} = \pi r^2$$

$$= \pi \times (4.66)^2$$

$$= 68.27\ m$$

$$= 68\,m$$

23. The graph below shows the velocity of a rocket as a function of time.



(a) Suggest what has happened at point X. [1]

– The rocket has burned all its fuel

(b) State and explain when the acceleration of the rocket is at a maximum. [2]

$a = \frac{F}{m}$

– As the rocket burns its fuel, its mass decreases, so its acceleration will increase.

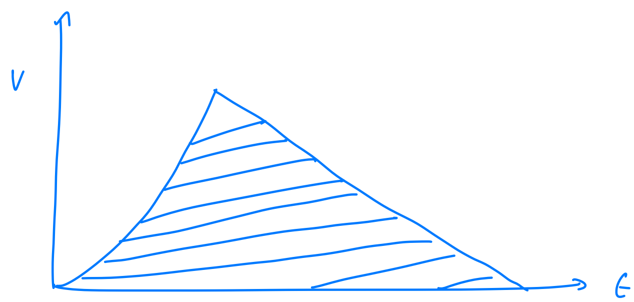
– Hence, a will be maximum right before the rocket runs out of fuel.

(c) Describe the subsequent motion of the rocket. [2]

- The rocket will continue to move upwards, but its acceleration will now be $-g$
- So the rocket will slow down and eventually come to a stop.

(d) Using the graph, how could the maximum height reached be determined? [1]

- For a v-t graph, the distance travelled is equal to the area under the graph.
- At maximum height, $v = 0$, so the maximum height is equal to the area below:



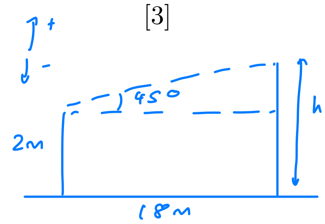
Section C

24. A 2 m tall birdwatcher with a mass of 100 kg is observing a nest. When standing 18m away from the tree, the line of sight to the nest makes an angle of 45° parallel to the ground.

    (a) The birdwatcher sees one egg fall. Ignoring air resistance, how long does it take to reach the ground? [3]

$h = 2 + (18 \times \tan(45))$

$= 20m$



S	U	V	A	T
$-h$	0		$-g$	?

$s = ut + \frac{1}{2}at^2$

$\Rightarrow h = \frac{1}{2}gt^2$ as $u = 0$

$\Rightarrow t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \times 20}{10}} = 2s$

    (b) How fast is the egg travelling when it reaches the ground? [2]

S	U	V	A	T
$-h$	0	?	$-g$	

$v^2 = u^2 + 2as$

$\Rightarrow v = \sqrt{2gh}$

$= \sqrt{2 \times 10 \times 20}$

$= 20ms^{-1}$

(c) On hitting the ground, the egg is brought to rest in 1 mm. Assuming a mass of 20 g for the egg, calculate the force required. (Assume a constant braking force). [3]

S	U	V	A	T
1×10^{-3}	20	0	?	

$$v^2 = u^2 + 2as$$

$$\Rightarrow \quad a = -\frac{u^2}{2s}$$

$$= -\frac{20^2}{2\times10^{-3}}$$

$$= 2\times10^{5}\ ms^{-2}$$

$$F = ma = -20\times10^{-3}\times 2\times10^{5}$$

$$= -4\times10^{3}\ N$$

(d) Calculate the work done by the braking force and compare it with the GPE of the egg. [3]

$$W = Fd$$

$$= 4\times10^{3}\times1\times10^{-3}$$

$$= 4\ J$$

– Initial GPE of the egg

$$E_p = mgh$$

$$= 20\times10^{-3}\times10\times20$$

$$= 4\ J$$

– So the initial GPE of the egg = the W.D by the breaking force.

(e) The egg smashes on impact. To prevent this happening again a pad of 10 cm thick foam is placed on the ground, under the tree. This foam compresses to half its initial thickness on impact. Find the new braking force when a second egg falls and the time taken to bring it to a halt. [3]

– Egg is brought to rest in 5cm

S	U	V	A	T
5×10^{-2}	20	0	?	?

$$v^2 = u^2 + 2as$$

$$\Rightarrow a = -\frac{u^2}{2s}$$

$$= -\frac{20^2}{2\times5\times10^{-2}}$$

$$= 4\times10^3\ ms^{-2}$$

$$F = ma = 20\times10^{-3}\times4\times10^3$$

$$= -80N$$

$$v = u + at$$

$$\Rightarrow t = \frac{v-u}{a}$$

$$= \frac{-20}{-4\times10^3}$$

$$= 5\times10^{-3}s$$

(f) The birdwatcher considers whether to return the second egg to the nest. Calculate the minimum energy that would be required for them to do this. [2]

– Minimum energy situation would be if the birdwatcher climbs the tree.

$$E = Mgh \quad , M = 100kg + 20g$$

$$= (100 + 0.02)\times10\times20$$

$$= 20004J$$

$$= 2\times10^4J$$

(g) Instead, the birdwatcher decides to keep the egg incubated by placing it in a cup of water and using a small electrical heater powered from a hand generator. Assuming there is 100 ml of water at 15°C with specific heat capacity of $4\,\mathrm{kJ\,kg^{-1}K^{-1}}$, calculate the maximum rate of heat loss from the system so that it requires no more energy to keep the egg incubated at 37°C for two weeks than it does to return it to the nest. [4]

- 100 ml (of water) = 0.1 kg
- Energy to initially heat the water is:

$$Q = mc\Delta\theta$$
$$= 0.1 \times 4\times10^3 \times (37-15)$$
$$= 8800\,J$$

- Let P = rate of heat loss
- So total energy to keep the egg incubated is

$$E = Q + Pt \quad , \; t = 2 \text{ weeks} = 1209600\,s$$

- We require

$$E < 20\times10^3\,J$$

$$\Rightarrow \quad Q + Pt < 20\times10^3$$

$$\Rightarrow \quad P < \frac{20\times10^3 - Q}{t}$$

$$= \frac{20\times10^3 - 8800}{1209600}$$

$$= 9.26\times10^{-3}\,W$$

$$\Rightarrow \quad P_{max} = 9\times10^{-3}\,W$$