90%

A*	A	B	C	D	E	
48	43	38	34	30	26	/60

OCR
Oxford Cambridge and RSA

Thursday 11 June 2015 – Morning

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G494/01 Rise and Fall of the Clockwork Universe

Candidates answer on the Question Paper.

OCR supplied materials:
- Data, Formulae and Relationships Booklet (sent with general stationery)

Other materials required:
- Electronic calculator
- Ruler (cm/mm)

Duration: 1 hour 15 minutes

Candidate forename	SA Worked Ans.	Candidate surname	

Centre number						Candidate number				

INSTRUCTIONS TO CANDIDATES

- Write your name, centre number and candidate number in the boxes above. Please write clearly and in capital letters.
- Use black ink. HB pencil may be used for graphs and diagrams only.
- Answer **all** the questions.
- Read each question carefully. Make sure you know what you have to do before starting your answer.
- Write your answer to each question in the space provided. If additional space is required, you should use the lined page at the end of this booklet. The question number(s) must be clearly shown.
- Do **not** write in the bar codes.

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets **[ ]** at the end of each question or part question.
- The total number of marks for this paper is **60**.
- You may use an electronic calculator.
- You are advised to show all the steps in any calculations.
- Where you see this icon you will be awarded marks for the quality of written communication in your answer.
  This means for example, you should
  - ensure that text is legible and that spelling, punctuation and grammar are accurate so that the meaning is clear;
  - organise information clearly and coherently, using specialist vocabulary when appropriate.
- The values of standard physical constants are given in the Data, Formulae and Relationships Booklet. Any additional data required are given in the appropriate question.
- This document consists of **16** pages. Any blank pages are indicated.

Answer **all** the questions.

SECTION A

1 Here is a list of units.

$N\,m\,kg^{-1}$ $N\,kg^{-1}$ $J\,m^{-1}$ $kg\,m\,s^{-1}$ $m\,s^{-1}$

(a) Which one is a correct unit for gravitational field strength?

$N\,kg^{-1}$ **[1]**

(b) Which one is a correct unit for gravitational potential?

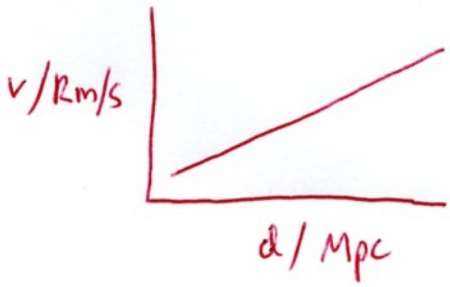
$J = Nm$ $(W = Fs)$

$Nm\,kg^{-1}$ **[1]**

2 The Big Bang theory states that the Universe has been expanding ever since it first appeared.

State and explain **one** piece of evidence for this theory.

The radial velocity of distant galaxies as measured by red shift of their spectra. leads to Hubble's Law $v = Hd$



[2]

OR

The cosmic microwave background is the red-shifted radiation from around 380,000 yrs after the Big Bang.

3 The half-life of π^+ mesons at rest in a laboratory is 18 ns. When a beam of fast-moving π^+ mesons move through the laboratory their measured half-life becomes 42 ns.

By calculating the relativistic factor γ for the π^+ mesons in the beam, determine their speed v through the laboratory.

$c = 3.0 \times 10^8\,\text{m s}^{-1}$

$\gamma = 42/18 = 2.33 = 1/\sqrt{1-v^2/c^2}$

$\therefore \sqrt{1-v^2/c^2} = 0.42$ & $1-v^2/c^2 = 0.184$

$\therefore \frac{v^2}{c^2} = 0.816$ $\therefore v^2 = 0.816\,c^2$ $v = \sqrt{0.816 c^2} =$

$v =$ ......2.7×10^8...... m s^{-1} **[3]**

4 Fig. 4.1 shows the situation before and after the collision of two spacecraft in empty space.

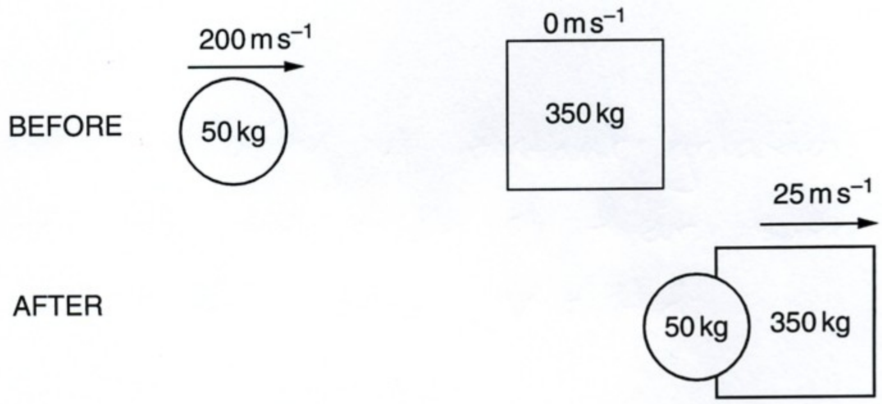


Fig. 4.1

(a) Use calculations to show that the collision conserves momentum but does **not** conserve kinetic energy.

$$\left.\begin{aligned} P_{initial} &= 200 \times 50 = 1\times10^4 \text{ kg m s}^{-1} \\ P_{final} &= 25 \times 400 = 1\times10^4 \text{ kg m s}^{-1} \end{aligned}\right\} \text{ same}$$

$$\left.\begin{aligned} E_{k\,initial} &= 50 \times 200^2/2 = 1\times10^6 \text{ J} \\ E_{k\,final} &= 400 \times 25^2/2 = 1.25\times10^5 \end{aligned}\right\} \text{ not same}$$

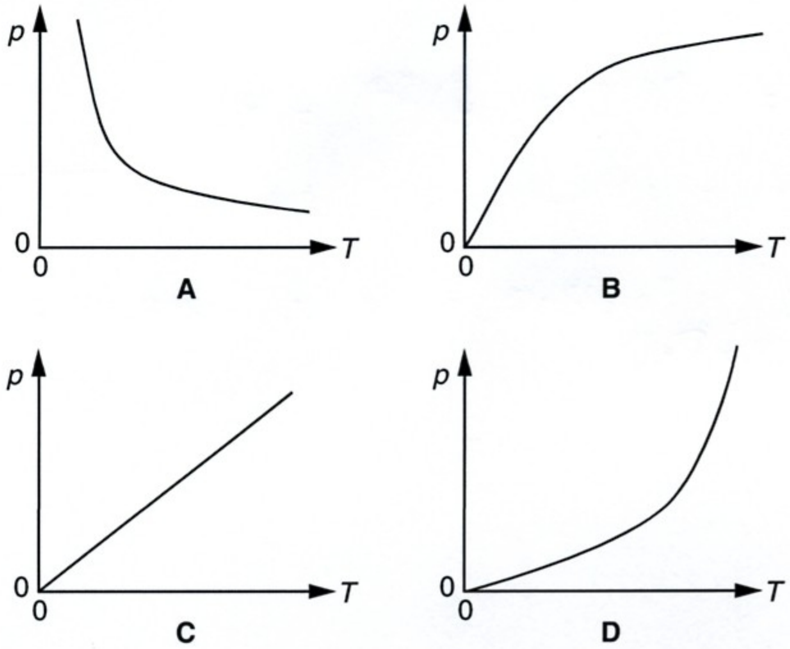
[3]

(b) Suggest why the collision does not conserve kinetic energy.

Enery used to deform spacecraft.

[1]

5 Which one of these four graphs **A**, **B**, **C** or **D** shows how the pressure p of a fixed mass of gas at a constant volume V changes with kelvin temperature T?



$PV = nRT$

$V\ n\ R$ are constant

$\therefore\ P \propto T$

answer ....C.......... **[1]**

6 A student calculates the motion of a mass of 0.25 kg suspended by a spring of force constant $50\,\mathrm{N\,m^{-1}}$. The mass is displaced vertically from equilibrium by 0.030 m at time $t = 0$ and released.

The student uses $\Delta v = -\frac{k}{m} x \Delta t$ followed by $\Delta x = v \Delta t$ to estimate the displacement of the mass at time $t = 0.10\,\mathrm{s}$.

$-\frac{k}{m} = -200$ $\qquad$ $-200 \times 0.03 \times 0.05$

(a) Complete the table.

t/s	v/m s^{-1}	x/m	Δt/s	Δv/m s^{-1}
0.00	0.00	0.030	0.05	−0.3
0.05	−0.3	0.015	0.05	−0.15
0.10	−0.45	−0.0075		

$0.015 + (-0.45 \times 0.05)$

[3]

(b) The student uses the relationship $x = A\cos(2\pi ft)$ to calculate the displacement of the mass at $t = 0.10\,\mathrm{s}$ as $+0.0047\,\mathrm{m}$.

Why is this value different from that obtained from the method of **(a)**?

method a) assumes velocity is constant during each 0.05s interval.

[1]

7 The table shows some measurements of air density at different temperatures at constant pressure.

Temperature / K	Density / kg m^{-3}
273	1.29
283	1.25
293	1.20
303	1.16

Kinetic theory suggests that the density ρ of an ideal gas with particles of mass m and pressure p is related to its kelvin temperature T by the equation

$$\rho = \frac{pm}{kT} \qquad \therefore \quad \rho T = \frac{pm}{T} = \text{const.}$$

where k is the Boltzmann constant.

Do the measurements support this equation? Justify your answer with calculations.

T	ρT
273	352
283	354
293	351
303	351

ρT is constant to 2 s.f. so yes they do support the equation

[2]

8 The equation $\frac{dN}{dt} = -\lambda N$ can be used to model the decay of a radioisotope.

Suggest how a value for the term λ can be determined experimentally for the radioisotope.

Measure activity (- background count) over time and enter data into spreadsheet. Fit exponential curve to data & display equation to give value for λ

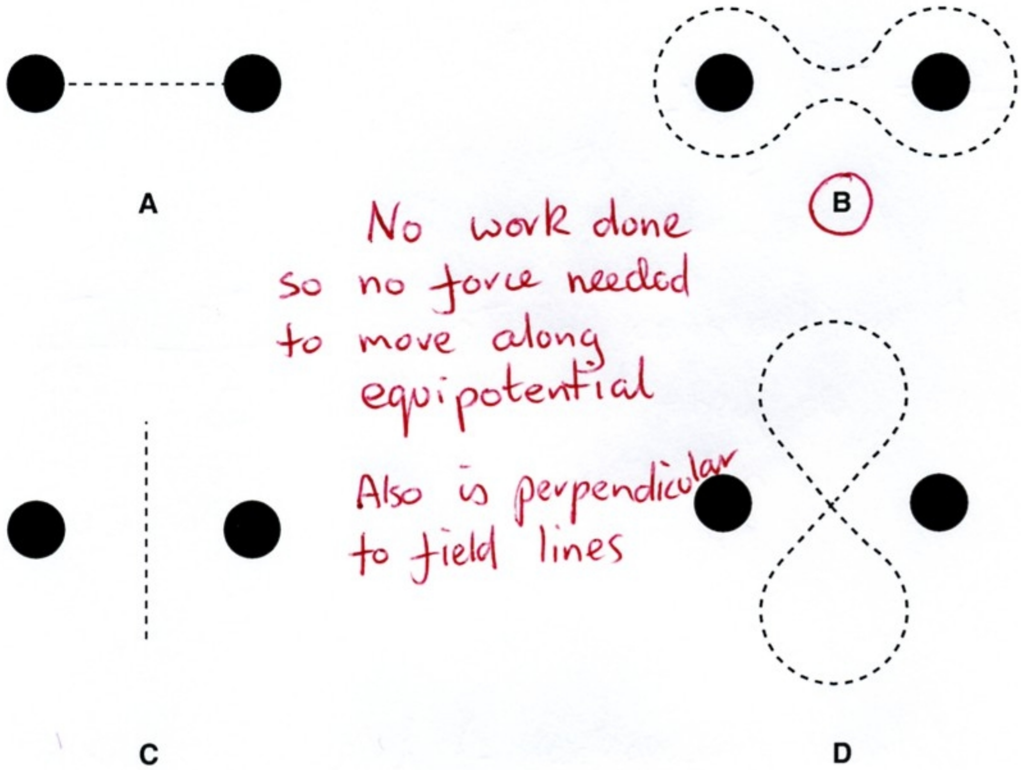
[1]

OR measure $t_{\frac{1}{2}}$ and use $\frac{\ln 2}{t_{\frac{1}{2}}} = \lambda$

9 Fig. 9.1 shows a binary star system. Both stars have the same mass and radius.

Fig. 9.1

Fig. 9.2 shows four different attempts to sketch a gravitational equipotential curve in the binary star system.
Which attempt **A**, **B**, **C** or **D** is correct?



No work done so no force needed to move along equipotential

Also is perpendicular to field lines

Fig. 9.2

answer ......B...... **[1]**

[Section A Total: 20]

SECTION B

10 This question is about possible flaws in an attempt to estimate a value for the gravitational constant G using Earth-based observations.

The table contains the results of data required.

radius of Earth at equator	6.4×10^6 m
mean density of surface rocks on Earth	2.7×10^3 kg m^{-3}
period of Moon's orbit around the Earth	2.4×10^6 s
time for a laser pulse fired at the Moon to return	2.5 s

(a) The Moon of mass m orbits the Earth of mass M in a circular path of radius r with a period T. By setting the centripetal force on the Moon equal to its gravitational attraction to the Earth, show that

$$G = \left(\frac{4\pi^2}{M}\right)\frac{r^3}{T^2}$$

$V = \frac{2\pi r}{T} \therefore v^2 = \frac{4\pi^2 r^2}{T^2}$

$\frac{mv^2}{r} = \frac{GMm}{r^2}$

$\therefore v^2 = GM/r$

$v^2 = \frac{4\pi^2 r^2}{T^2} = \frac{GM}{r} \therefore G = \frac{4\pi^2 r^3}{T^2 M}$

[3]

(b) The mass M of the Earth can be estimated from its radius R and its density ρ.

Use the data for radius and density in the table to show that they give a value of M which is about 3×10^{24} kg.

$V = \frac{4}{3}\pi r^3 = 1.098 \times 10^{21}\ m^3$

Mass = vol × density = $1.098 \times 10^{21} \times 2.7 \times 10^3$

[2]

$= 2.96 \times 10^{24}$ kg

(c) The distance r from the centre of the Earth to the centre of the Moon can be estimated by timing the return of laser pulses reflected from the Moon's surface.
The relationship $r = \frac{c\Delta t}{2}$ can be used to estimate a value for r from the time interval Δt between the emission and return of a laser pulse.

(i) State **two** assumptions required for the relationship to be valid.

speed of light is constant throughout journey
out and return journey times are equal
(can ignore relatively small radius of E & M) **[2]**

(ii) Use the data from the table to calculate a value for r and hence show that the value of G obtained from **(a)** and **(b)** is very different from the accepted value of $6.7 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$.

$c = 3.0 \times 10^{8}\,\mathrm{m\,s^{-1}}$

$$r = \frac{3 \times 10^{8} \times 2.5}{2} = 3.75 \times 10^{8}\ \mathrm{m}$$

$$G = \frac{4\pi^2 \times (3.75 \times 10^{8})^3}{3 \times 10^{24} \times (2.4 \times 10^{6})^2} =$$

$G =$ 1.2×10^{-10} $\mathrm{N\,m^2\,kg^{-2}}$ **[2]**

(iii) Suggest a reason why your calculated value of G is very different from the accepted value. Justify your answer.

Value for G is too large as value for M will be too small as it was based on density of rock at surface. Rocks in mantle & core have higher density. **[2]**

11 This question is about the pressure of the atmosphere.

(a) Use the behaviour of air molecules to explain how the Earth's atmosphere exerts a pressure on the ground.

Your answer should clearly link the behaviour of the molecules to gas pressure.

Momentum transferred to ground

$\Delta p = 2mv$

Gas molecules collide with ground and experience a change in momentum of 2mv. This change in momentum results in a force and Pressure = Force/Area.

[3]

(b) The equation $pV = \frac{1}{3} Nm\overline{c^2}$ relates the mean square speed $\overline{c^2}$ of N gas molecules of mass m to the pressure p and volume V of an ideal gas.

(i) By assuming that air at 20 °C is an ideal gas, show that the root mean square speed of its molecules is about 500 m s^{-1}.

$m = 4.7 \times 10^{-26}$ kg
$k = 1.4 \times 10^{-23}$ J K^{-1}

$pV = \frac{1}{3} Nm\overline{c^2} = NkT$

$\therefore \overline{c^2} = \frac{3kT}{m} = 2.62 \times 10^5$

RMS speed $= \sqrt{\overline{c^2}} = \sqrt{2.62 \times 10^5} = 512 \text{ ms}^{-1}$

[3]

(ii) Atmospheric pressure at 20 °C is typically 1.0×10^5 Pa.

Estimate the rate at which air molecules collide with an object of surface area $0.56\,m^2$ to provide this pressure.

State **one** assumption you have to make. $P = F/A \;,\; F = \frac{\Delta mv}{\Delta t}$

$F = PA = 1.0\times10^5 \times 0.56m^2 = 5.6\times10^4\ N$

$F = \frac{2\Delta mv}{\Delta t} \quad \therefore\ 2\Delta mv = 5.6\times10^4 \quad (\Delta t = 1\ sec)$

$\therefore \Delta m = 5.6\times10^4/512\times2 = 54.7\ kg$

No of molecules (collisions) $= \frac{54.7}{4.7\times10^{-26}} =$

collision rate = 1.16×10^{27} s^{-1} **[4]**

12 **(a)** The circuit shown in Fig. 12.1 is used to determine the capacitance of a capacitor.

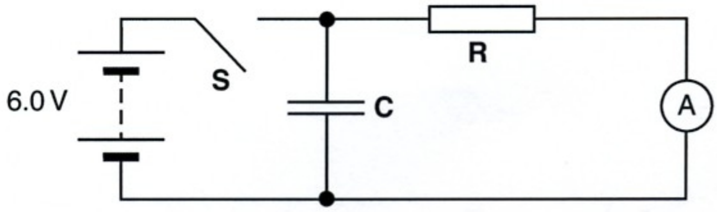


Fig. 12.1

The switch **S** is closed at time $t = 0$ s. This allows the 6.0 V battery to charge the capacitor **C**. The switch is then opened at time $t = 20$ s, allowing the capacitor to discharge through resistor **R**. The graph of Fig. 12.2 shows how the current I in the ammeter varies with time.

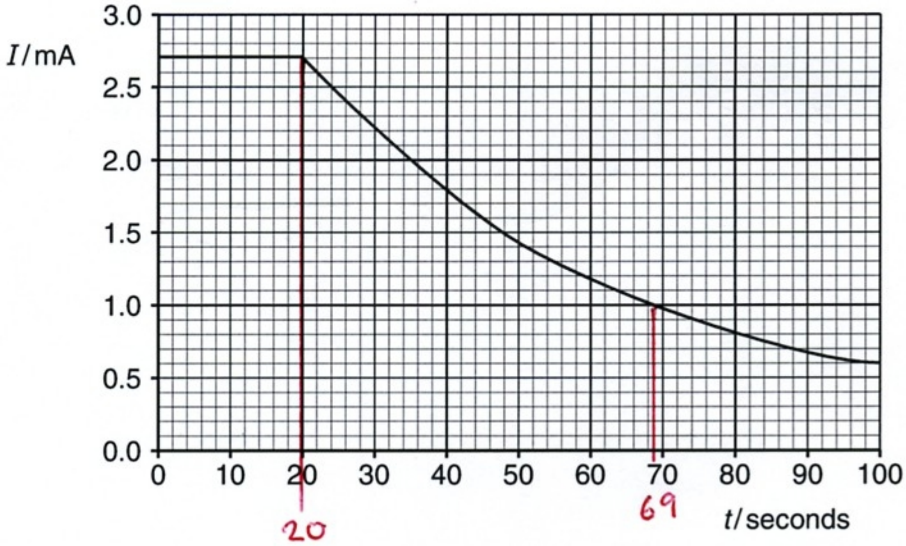


Fig. 12.2

Use the data to

(i) show that **R** has a value of about 2 kΩ

$R = V/I = 6/2.7 \times 10^{-3} = 2222\ \Omega$

[1]

(ii) calculate a value C for the capacitance of **C**.

$RC = \tau$ = time for Q (& hence V & I) to fall to 37% of initial value.

$C =$ 0.022 F **[2]**

37% of 2.7 = 1.0 V

time = 69 − 20 = 49 s

$49\text{s}/2222\ \Omega = 0.022$

(b) A 470 μF capacitor is placed in the circuit of Fig. 12.3.

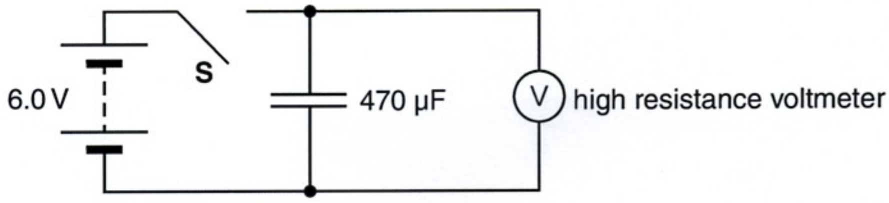


Fig. 12.3

When the switch **S** is opened, the reading on the voltmeter decreases by 0.12 V in 60 s. This is because the insulator which separates the capacitor plates does not have infinite resistance. Charge is able to flow directly from one plate to another through the insulator, making a *leakage current*.

(i) Calculate the leakage current in the insulator.

$C = Q/V \;\therefore\; Q = CV = 470 \times 10^{-6} \times 0.12\,V = 5.64 \times 10^{-5}\,C$

$I = Q/t = 5.64 \times 10^{-5}/60 = 9.4 \times 10^{-7}\,A$

leakage current = ...0.94...... μA **[2]**

(ii) Leakage current increases with temperature. The Boltzmann factor can be used to predict that the leakage current I is related to the temperature T by the equation $I = Ae^{-\varepsilon/kT}$, where A is a constant.

Suggest the meaning of the quantity ε in this equation.

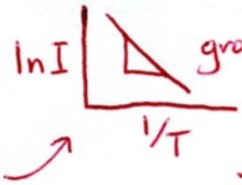
Energy needed for electron to conduct in the insulator / jump to conduction band

[2]

(iii) The leakage current rises from 1.0 μA to 10 μA as the temperature of the capacitor increases from 300 K to 400 K. Calculate the value of ε.

$k = 1.4 \times 10^{-23}\,JK^{-1}$

$$\boxed{\begin{aligned} \ln I &= -\frac{\varepsilon}{k}\,\frac{1}{T} + \ln A \\ y &= m\,x + c \end{aligned}}$$



grad $= \frac{-\varepsilon}{k}$

$\therefore \varepsilon = -\text{grad} \times k$

$$\text{gradient} = \frac{\ln(1 \times 10^{-6}) - \ln(10 \times 10^{-6})}{1/300 - 1/400}$$

$= -2763$

$\varepsilon = -2763 \times 1.4 \times 10^{-23} =$

ε = ...3.9×10^{-20}...... J **[2]**

13 This question is about avoiding resonant oscillations in an earthquake.

The lift in a skyscraper can be modelled as a mass suspended by a spring from the top of the building. The lift will therefore have a natural frequency of vertical oscillations f_0. If the value of f_0 lies within the range 2 Hz–0.2 Hz, there is a risk that surface waves from an earthquake will set the lift into resonance.

(a) Explain why it is important to design the lift so that it cannot be easily set into resonance.

Amplitude of oscillation will become large and the cable strain may exceed safe limits and snap. It would also shake any occupants up & down! **[2]**

(b) Fig. 13.1 shows a lift cage suspended by steel cables from the top of a tall building. Here are some data for a typical lift.

mass of empty cage	1500 kg
maximum load of 8 people	640 kg
maximum length of cable	300 m
overall cross-sectional area of cables	$2.5 \times 10^{-4}\,m^2$
Young modulus of steel	2.0×10^{11} Pa
yield stress of steel	2.5×10^{8} Pa

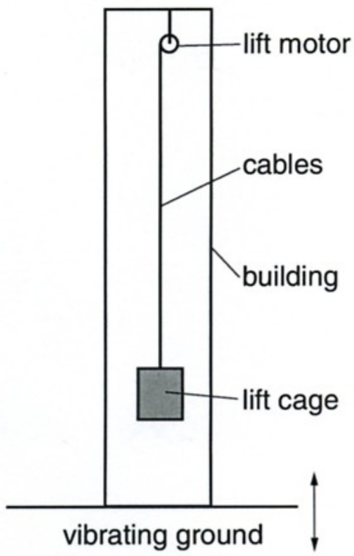


Fig. 13.1

(i) Show that the force constant k of a cable of length L, cross-sectional area A and Young modulus E is given by

$$k = \frac{EA}{L}$$

$E = \frac{FL}{Ax} \therefore x = \frac{FL}{EA}$ (1)

$F = kx \therefore k = \frac{F}{x}$ (2)

sub (1) into (2) $\quad k = \frac{EAF}{FL} = \frac{EA}{L}$ **[2]**

(ii) Use calculations to show that the lift is in danger of resonance from earthquake waves when it contains a maximum load and the cables are at their maximum length.

$$T = 2\pi\sqrt{\frac{m}{K}} = 2\pi\sqrt{\frac{mL}{EA}} = 2\pi\sqrt{\frac{(1500+640)\times 300}{2\times 10^{11}\times 2.5\times 10^{4}}}$$

$= 0.71\,s \quad f = 1/T = 1/0.71 = 1.4\ Hz$

1.4 Hz is in the 0.2 – 2 Hz range.

[3]

(c) (i) Suggest why it is impractical to make the lift safe from resonance by adding some damping.

During operation the lift needs to move freely up and down the shaft.

[1]

(ii) Suggest and explain **one** other practical modification to the lift which would reduce the risk of resonance in an earthquake.

Your answer should clearly explain how your suggestion reduces the risk.

Increase mass of lift so that natural frequency falls below the 0.2 – 2 Hz range. As $f = \frac{1}{2\pi}\sqrt{\frac{K}{m}}$ a higher mass gives lower frequency.

[2]

[Section B Total: 40]

END OF QUESTION PAPER