VICTORIA JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME	**SOLUTION**

CLASS		TUTOR NAME	

PHYSICS **9749/02**

Paper 2 Structured Questions **16 September 2025**

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class and tutor name in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use a HB pencil for any diagrams, graphs.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.
Answer **all** questions.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	/ 7
2	/ 8
3	/ 8
4	/ 9
5	/ 8
6	/ 12
7	/ 10
8	/ 19
Total	/ 80

This document consists of **24** printed pages.

Data

speed of light in free space	$c = 3.00 \times 10^{8}$ m s^{-1}
permeability of free space	$\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
	$(1 / (36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	$e = 1.60 \times 10^{-19}$ C
the Planck constant	$h = 6.63 \times 10^{-34}$ J s
unified atomic mass constant	$u = 1.66 \times 10^{-27}$ kg
rest mass of electron	$m_e = 9.11 \times 10^{-31}$ kg
rest mass of proton	$m_p = 1.67 \times 10^{-27}$ kg
molar gas constant	$R = 8.31$ J K^{-1} mol^{-1}
the Avogadro constant	$N_A = 6.02 \times 10^{23}$ mol^{-1}
the Boltzmann constant	$k = 1.38 \times 10^{-23}$ J K^{-1}
gravitational constant	$G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
acceleration of free fall	$g = 9.81$ m s^{-2}

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
work done on / by a gas	$W = p\Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential	$\phi = -Gm / r$
temperature	$T / \text{K} = T / {}^\circ\text{C} + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V} < c^2 >$
mean translational kinetic energy of an ideal molecule	$E = \frac{3}{2}kT$
displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$
	$= \pm\omega\sqrt{x_0{}^2 - x^2}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = \frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

1 A golfer is practising his tee shot from a platform 7.0 m off the ground as shown in Fig. 1.1. The golf ball was launched at a speed of 50 m s^{-1}, 40° above the horizontal. Assume air resistance is negligible.

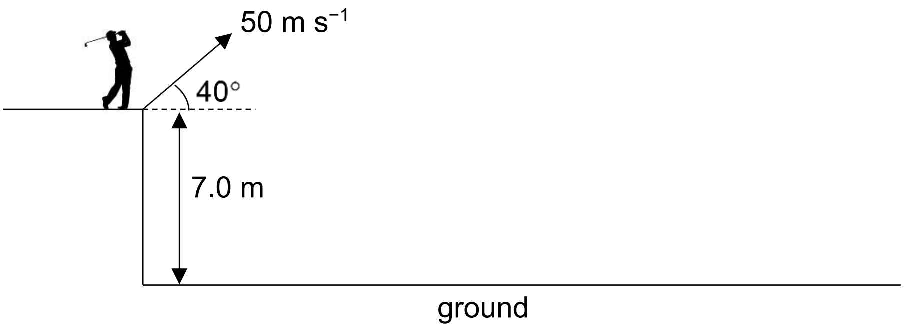


Fig 1.1

(a) Determine the maximum height above the ground attained by the ball.

Initial vertical velocity $u_y = 50 \sin 40° = 32.139$ m s^{-1} [1]

At the top of flight the vertical velocity $v_y = 0$ m s^{-1}

Can also solve via energy considerations

Using $v_y^{\,2} = u_y^{\,2} + 2as$, taking up as positive, we get

$0 = 32.139^2 + 2(-9.81)s$

$s = 52.647$ m [1]

Max height = 52.647+7.0 = 59.647 = 60 m [1]

maximum height = ... m [3]

(b) Calculate the time of flight of the ball.

When ball touches the ground $s_y = -7.0$ m

Using $s_y = u_y t + \frac{1}{2}at^2$,

$-7 = 32.139t + \frac{1}{2}(-9.81)t^2$ [1]

$t = -0.211$ s (reject) or $t = 6.7639 = 6.8$ s [1]

time of flight = ... s [2]

(c) A golf ball typically bounces a few times after a tee shot as shown in Fig. 1.2. The first time the ball touches the ground is indicated by A and the fourth time it touches the ground is indicated by B. Take the upward direction as positive.

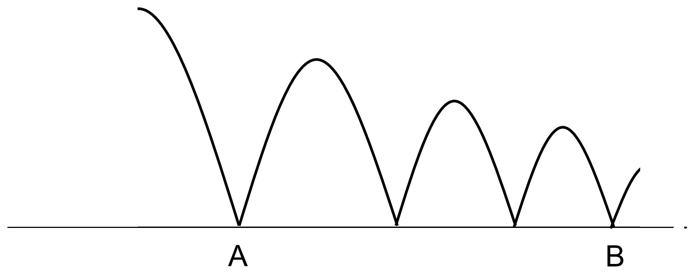


Fig. 1.2

Sketch, on Fig. 1.3, a graph to show the variation with time of the vertical velocity of the ball between from the instant it leaves A to the instant it reaches B.

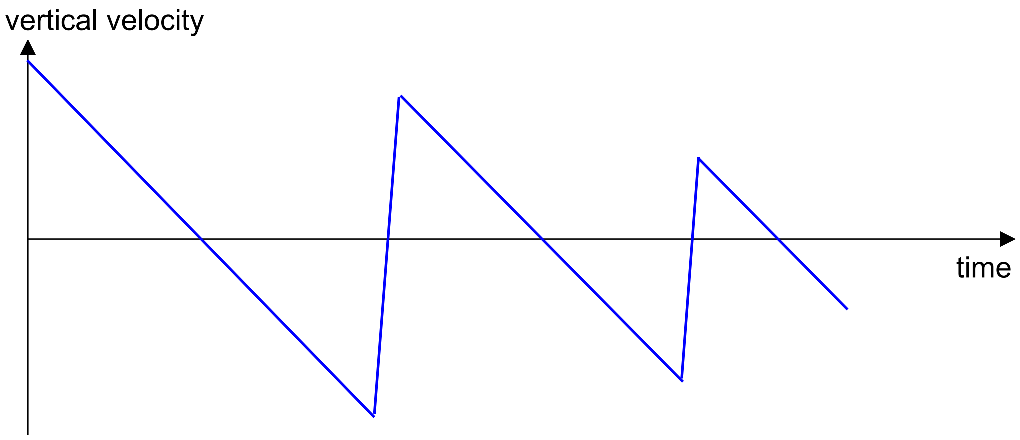


Fig. 1.3

3 parallel lines, same gradient, in between bounces; with vertical lines (or very slight slant) when ball is in contact with ground. [1]
Speed after rebound is lower than speed before rebound and area above and below graph are equal [1]

[2]

[Total: 7]

2 **(a)** Define Newton's second law.

The rate of change of momentum of a body is proportional to the resultant external force acting on it and is in the direction of the resultant force.

....[1]

(b) A light rope is attached to a 120 kg box on the ground. The other end of the rope runs over a light frictionless pulley.

A 80 kg man climbs up the free-hanging rope. As the man climbs up the rope, he pulls on the rope hard enough to cause himself to accelerate upwards. The only point of contact between the rope and the man occurs at his hands.

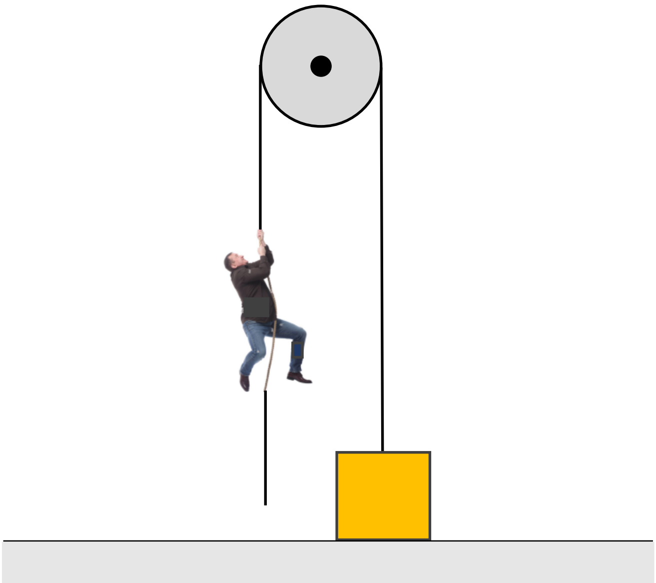


Fig. 2.1

(i) Draw, on the outline of the man in Fig. 2.2, the forces acting on the man as he climbs.

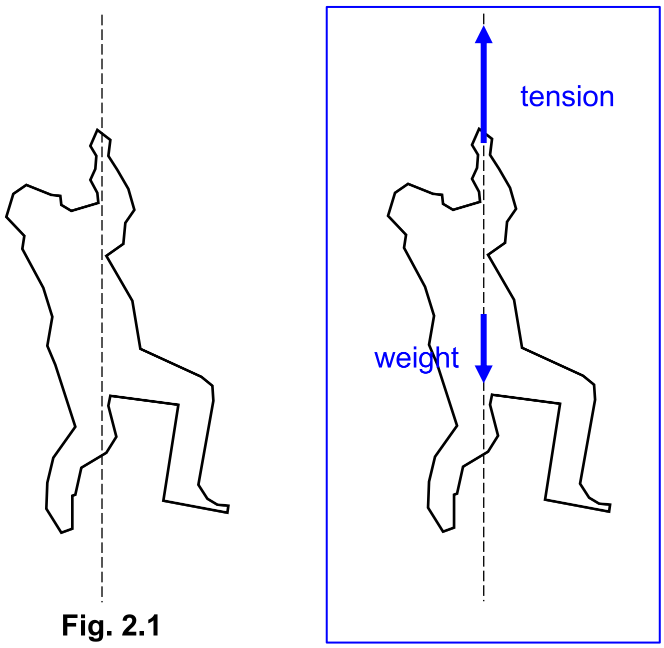


Fig. 2.1

[1]

(ii) If the man climbs the rope with an acceleration of 8.0 m s^{-2}, determine the acceleration of the box.

Let m = mass of man.
Let M = mass of box.

Apply $F = ma$ to man:
$T - mg = m\,a_{man}$
$T = m\,(g + a_{man})$ ---(1)

Apply $F = ma$ to box:
$T - Mg = M\,a_{box}$ ---(2)

Sub. T from (1) into (2):
$m\,(g + a_{man}) - Mg = M\,a_{box}$
$80\,(9.81 + 8.0) - 120 \times 9.81 = 120\,a_{box}$
a_{box} = 2.1 m s^{-2}.

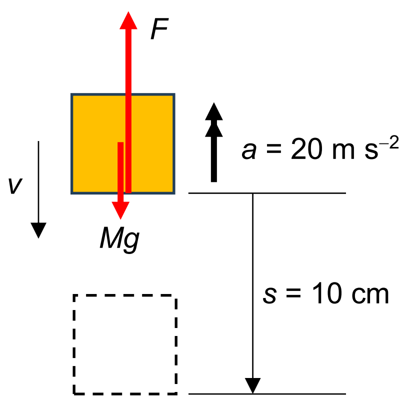
acceleration = ... m s^{-2} [2]

(c) The man releases the rope and the box falls. The box hits the ground with a speed of 2.0 m s^{-1} and sinks into the ground over a vertical distance of 10 cm before coming to a stop.

Calculate the force exerted by the ground on the box during the deceleration.

$v^2 = u^2 + 2as$
$0 = 2.0^2 + 2a(0.10)$
$a = -20$ m s^{-2}

Apply $F = ma$ to box:
$F - Mg = Ma$
$F - 120 \times 9.81 = 120 \times 20$
F = 3600 N



force = ... N [3]

[Total: 8]

3 A peg is fixed to the rim of a vertical turntable of radius r rotating with a constant angular speed ω, as shown in Fig. 3.1.

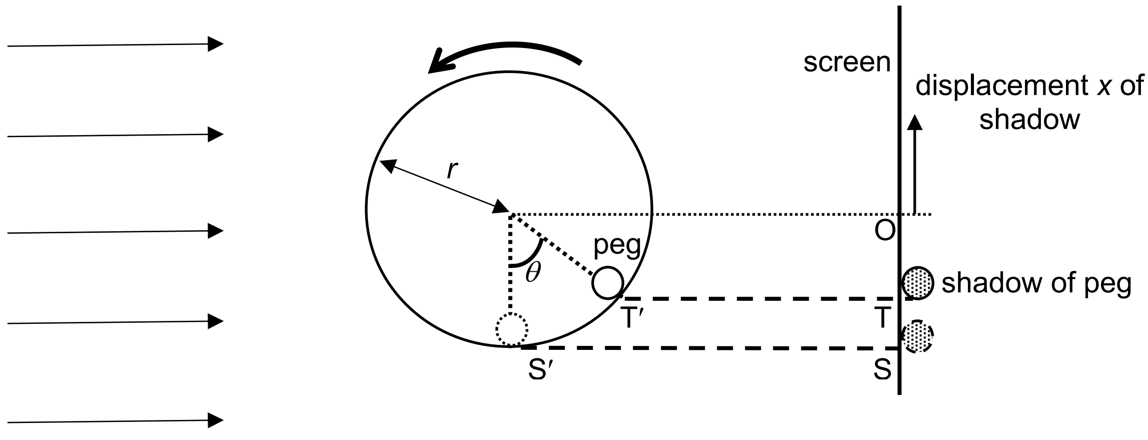


Fig. 3.1

A parallel beam of light is incident on the turntable such that the shadow of the peg is observed on the screen. Initially, the peg is at position S′ and its shadow is at S. After time t, the peg moves through an angle of θ and it is positioned at T′ while its shadow is at T.

The displacement x of the shadow from O is shown in Fig. 3.1 where the upward direction is taken to be positive.

(a) **(i)** Express the angular displacement θ of the peg in terms of ω and t.

$\theta = \omega t$

[1]

(ii) Write down an expression for the displacement x of the shadow on the screen in terms of ω, t and r.

$x = -r\cos\omega t$

[1]

(iii) Hence, prove that the shadow of the peg is moving in simple harmonic motion. Explain your working.

$x = -r\cos\omega t$

$v = \dfrac{dx}{dt} = r\omega\sin\omega t$

$a = \dfrac{dv}{dt} = r\omega^2\cos\omega t = -\omega^2\left(-r\cos\omega t\right) = -\omega^2 x$

which is the defining equation of a simple harmonic motion.

[2]

(b) The turntable has a radius of 20.0 cm and angular speed of 3.5 rad s^{-1}. For the motion of the shadow on the screen,

(i) calculate the acceleration of the shadow when the shadow is instantaneously at rest,

$$a = -\omega^2 x$$
$$= -3.5^2 (0.200)$$
$$= -2.45 \text{ m s}^{-2}$$

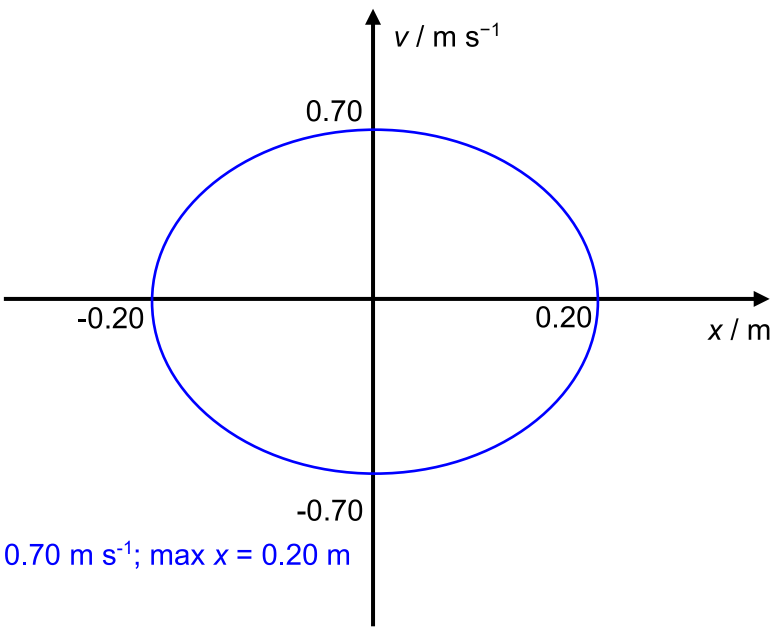
acceleration = ... m s^{-2} [1]

(ii) determine the velocity of the shadow as it passes through O,

$$v_{max} = \omega x_0$$
$$= 3.5(0.200)$$
$$= 0.700 \text{ m s}^{-1}$$

velocity = ... m s^{-1} [1]

(iii) sketch the variation with displacement x of the velocity v of the shadow.



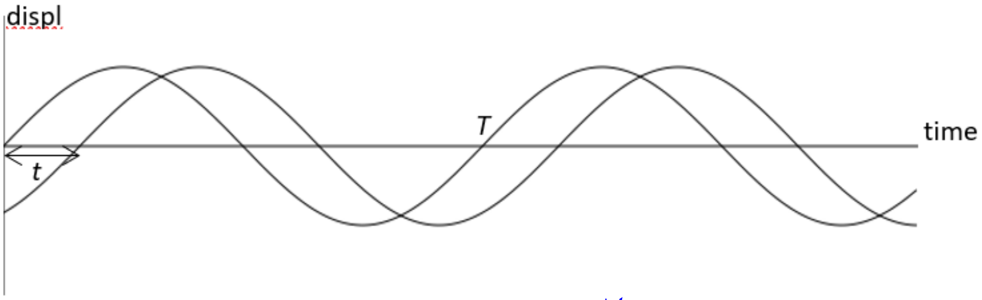
max v (y intercept) = 0.70 m s^{-1}; max x = 0.20 m

[2]

[Total: 8]

4 **(a)** Two waves are of the same frequency.

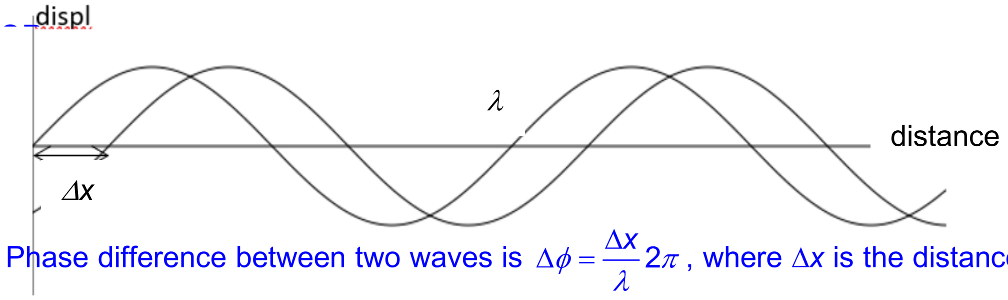
Explain with the aid of a diagram what, for the two waves, is meant by *phase difference*.



[1]

Phase difference between two waves is $\Delta\phi = \frac{\Delta t}{T}2\pi$, where Δt is the time between two corresponding points, e.g. crest and crest or trough and trough on the two waves, and T is the period of the wave. [1]

....[2]



Phase difference between two waves is $\Delta\phi = \frac{\Delta x}{\lambda}2\pi$, where Δx is the distance between two corresponding points, e.g. crest and crest or trough and trough on the two waves, and λ is the wavelength of the wave. [1]

[1]

(b) Monochromatic light is incident normally on a double slit as shown in Fig. 4.1. Light passes through the two slits B and C and is incident on the screen.

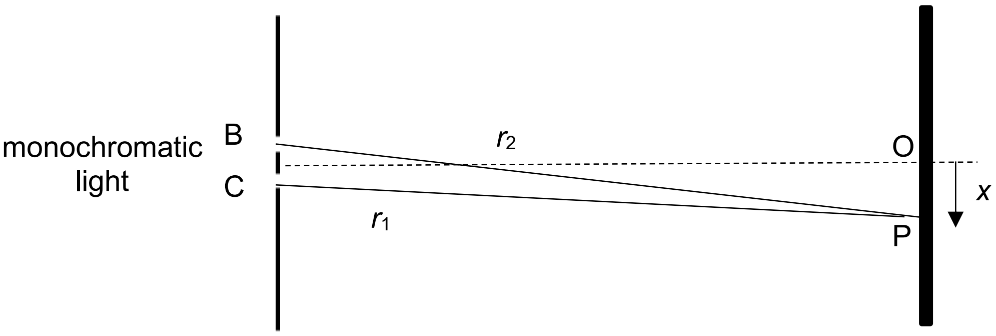


Fig. 4.1

The centre of the interference pattern formed on the screen is at O. The separation between the fringes is y.

r_1 and r_2 are two waves arriving at P.

(i) **1.** Deduce the relationship between the phase difference of the two waves arriving at point P and the distance x from point O.

$$\frac{\Delta\phi}{2\pi} = \frac{x}{y}$$

$$\Delta\phi = \frac{2\pi x}{y}$$

[1]

2. The waves have a phase difference of 12.6 radians when they meet at point P. Distance OP on the screen is 5.2 mm. Calculate the separation y between the fringes.

$$\Delta\phi = \frac{2\pi x}{y}$$

$$y = \frac{2\pi x}{\Delta\phi}$$

$$= \frac{2\pi \times 5.2}{12.6} \qquad [1]$$

$$y = 2.6 \text{ mm} \qquad [1]$$

y = ... m [2]

(ii) The light is adjusted so that the intensity of the light passing through slit B is reduced to a quarter that through slit C. The intensity of light from slit C alone at O is I. Deduce in terms of I, the intensity of the light at O due to the two slits.

Intensity $I = kA^2$ where k is a constant.

The amplitude of light from B is then $\frac{A}{2}$ [1]

The total intensity at O is thus $k\left(\frac{A}{2} + A\right)^2 = 2.25kA^2 = 2.25I$ [1]

intensity = ... [2]

(iii) Sketch, on Fig. 4.2, a graph to show the variation with distance x from point O of the intensity of light observed on the screen. Label your answer to **(b)(ii)** on Fig. 4.2. Ignore the single slit diffraction envelope.

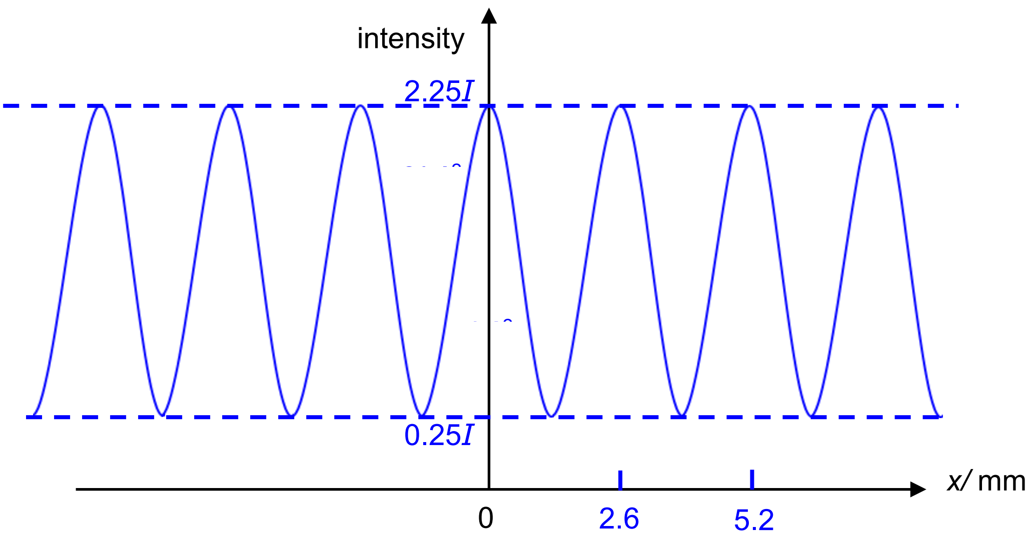


Fig. 4.2

[1m for max and min intensities at $2.25I$ and $0.25I$ respectively. 1m for constant fringe separation]

[2]

[Total: 9]

5 Fig. 5.1 below shows an isolated, metal sphere in a region of vacuum that carries a negative electric charge.

E-field lines: directed radially towards centre of sphere, equally spaced around sphere, giving a symmetrical pattern. There should be no field lines inside sphere.

Equipotential lines: concentric circles perpendicular to field lines, spacing is further apart with distance from centre

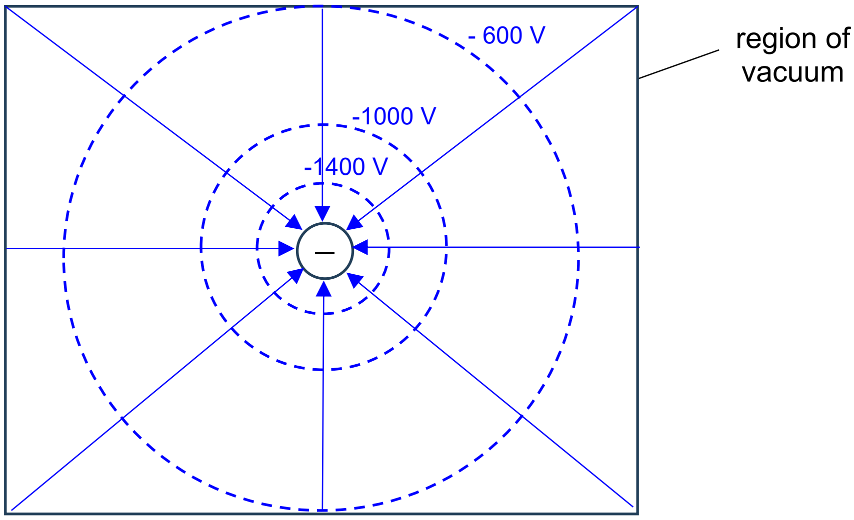


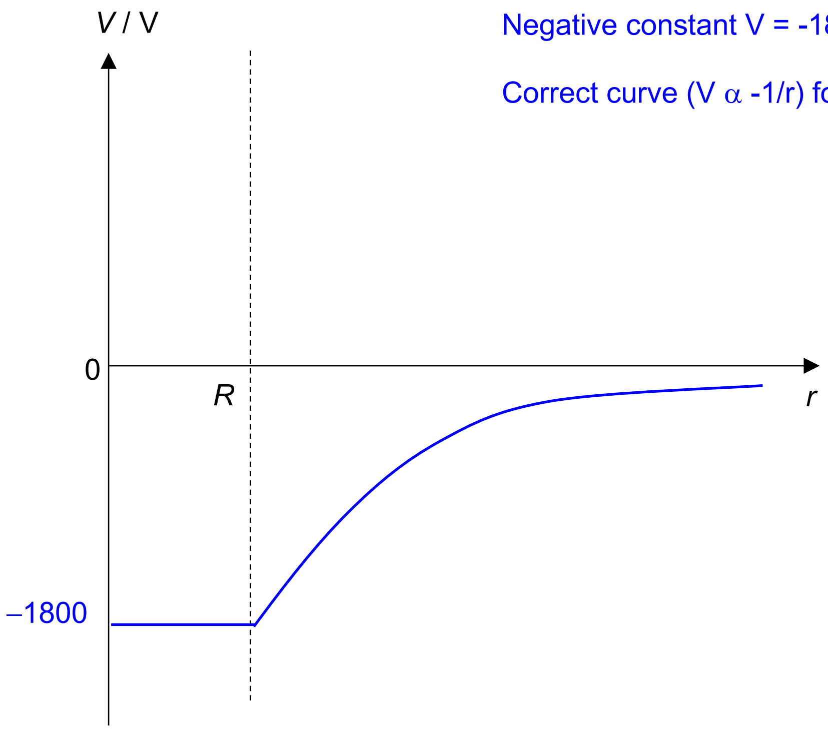
Fig. 5.1 (not to scale)

(a) The electric potential at the surface of the sphere is –1800 V. In the region of vacuum on Fig. 5.1, draw

(i) arrows to represent the electric field pattern outside the sphere [1]

(ii) dotted lines to represent three equipotential surfaces of –1400 V, –1000 V and –600 V outside the sphere. Label the potentials clearly. [1]

(b) On the axes given in Fig. 5.2, sketch a graph to show the variation with distance *r* from the centre of the sphere of the potential *V*. The dotted line is drawn at *r* = *R* where *R* is the radius of the sphere.



Negative constant V = -1800 V for r ≤ R [1]

Correct curve (V α -1/r) for r ≥ R [1]

Fig. 5.2

[2]

(c) The sphere carries an electric charge of –9.0 nC and has a radius of 4.5 cm. An electron is initially at rest at the surface of the sphere.

(i) Describe the motion and path followed by the electron as it leaves the surface of the sphere.

Electron accelerates or speed increases [1]
as it moves radially outwards/perpendicular to surface of sphere (along a field line) [1]

....

....[2]

(ii) Determine the speed of the electron when it reaches a point a distance 0.30 m from the centre of the sphere.

By conservation of energy,
Loss in EPE = gain in KE
$q\,[\,Q/(4\pi\varepsilon_0\,(0.045)) - Q/(4\pi\varepsilon_0\,(0.30))\,] = \frac{1}{2} m v^2 - 0$ or $q\,[\,(-1800) - Q/(4\pi\varepsilon\,(0.30))\,] = \frac{1}{2} m v^2 - 0$

$(-1.6 \times 10^{-19})\times(-9.0 \times 10^{-9})\times[\,1/(4\pi\varepsilon\,(0.045)) - 1/(4\pi\varepsilon\,(0.30))] = \frac{1}{2}(9.11 \times 10^{-31})\,v^2 - 0$ [1]
$v = 2.3 \times 10^{7}$ ms^{-1} [1]

speed = ... m s^{-1} [2]

[Total: 8]

6 (a) A length of copper wire of cross-sectional area 1.2×10^{-6} m^2 carries a steady current of 2.5 A. The wire has a density of 8.9×10^3 kg m^{-3}. Assume the wire is made entirely of copper atoms, each contributing one free electron to conduction. The molar mass of copper is 63.5 g mol^{-1}.

Calculate the average drift velocity of the electrons in the wire.

number density $n = \dfrac{\text{No. of atoms}}{\text{Volume}} = \dfrac{\text{mass}}{\text{(molar mass)(Volume)}} \times N_A$

$= \dfrac{\text{density}}{\text{molar mass}} \times N_A$

$= \dfrac{8.9 \times 10^3}{0.0635} \times 6.02 \times 10^{23}$ [1]

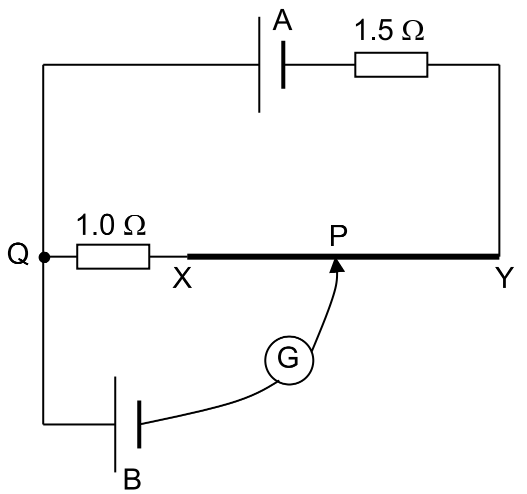
Drift velocty $v = \dfrac{I}{neA}$ [1]

$= \dfrac{(2.5)(0.0635)}{(8.9 \times 10^3)(6.02 \times 10^{23})(1.6 \times 10^{-19})(1.2 \times 10^{-6})}$

$= 1.5 \times 10^{-4}$ m s^{-1} [1]

average drift velocity = ... m s^{-1} [3]

(b) In the circuit below, cell A has an e.m.f. 2.0 V and negligible internal resistance. Wire XY is 100.0 cm long with a resistance of 5.0 Ω.



(i) Distinguish between *electromotive force e.m.f.* and *potential difference p.d.* using energy considerations.

E.m.f. is the electrical energy converted from other forms of energy per unit charge delivered by the source. *P.d.*is the electrical energy converted to other forms of energy per unit charge when charges pass from one point to another. [1]

(ii) Calculate the current flowing from Q to Y when the galvanometer registers a null deflection.

When the galvanometer registers a null deflection, no current in the lower circuit.

$I = \frac{2.0}{1.0 + 5.0 + 1.5}$ [1]

$= 0.27$ A [1]

current = ... A [2]

(iii) Cell B has an e.m.f. of 1.5 V. At balance point P,

1. show that resistance across X and P is 4.6 Ω,

At balance point, $V_{QP} = \varepsilon_B = 1.5$ V [1]

By the potential divider principle,

$V_{QP} = \frac{1.0 + R_{XP}}{R_{total}} \times \varepsilon_A$

$1.5 = \frac{1.0 + R_{XP}}{1.0 + 5.0 + 1.5} \times 2.0$ [1]

$R_{XP} = 4.625\ \Omega = 4.6\ \Omega$ (2 s.f.)

[2]

2. calculate the balance length XP.

$\frac{L_{XP}}{L_{XY}} = \frac{R_{XP}}{R_{XY}}$ [1]

$L_{XP} = \frac{4.625}{5.0} \times 1.0 = 0.925$ m [1]

length XP = ... m [2]

(iv) State and explain how the length XP in **(b)(iii)2.** will change if the internal resistance of cell A is not negligible.

From potential divider principle, the p.d. across the wire XY will now be smaller. [1]
Hence length XP will be longer. [1]
....[2]

[Total: 12]

7 X-rays are produced when electrons accelerated by a large electrical potential difference impinge upon a metal target. The X-ray spectrum of copper shown in Fig. 7.1 is produced by bombarding a copper target with high-energy electrons. The spectrum consists of two main components: a continuous spectrum (bremsstrahlung) and a line spectrum (characteristic X-rays).

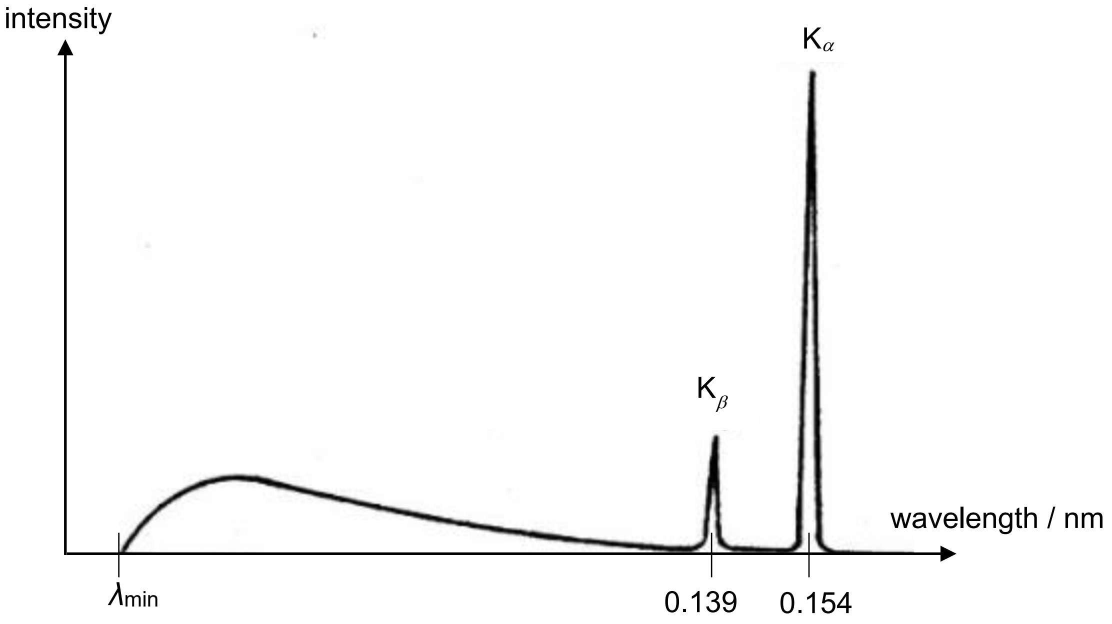


Fig. 7.1

(a) Explain the shape of:

(i) the continuous spectrum,

The bombarding electrons can lose any fraction of their initial kinetic energy, up to the maximum in a single interaction.[1] As a large number of electrons lose differing amounts of kinetic energies, X-ray photons of various wavelengths are emitted, resulting in a continuous X-ray spectrum represented by the solid line. [1] [2]

(ii) the sharp peaks in the spectrum.

When a fast bombarding electron knocks out an inner shell electron from a target atom, a vacancy is created. An electron in the outer shell de-excites to fill the vacancy, emitting an X-ray photon. [1] X-ray photons emitted in such de-excitations have energies that are equal to the energy differences between the energy levels of the two shells, hence producing X-rays of specific frequencies that appear as sharp peaks in the spectrum. [1] [2]

(b) **(i)** Calculate the energy of a K_α photon.

K_α photons have lower energy (and hence longer wavelength) than K_β photons.

λ = 0.154 nm

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{0.154 \times 10^{-9}}$$

$E = 1.29 \times 10^{-15}$ J = <u>8070 eV</u>

energy = ... eV [1]

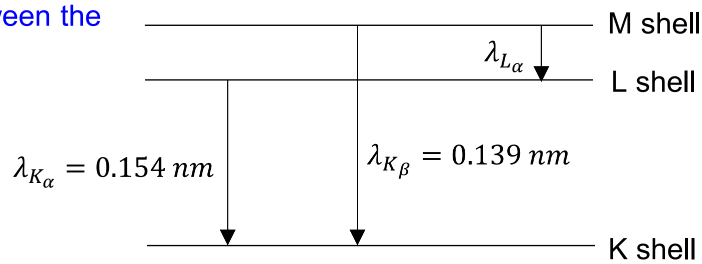
(ii) L_α photons are emitted when inner shell electrons de-excite from the M shell to the L shell. Calculate the wavelength of the L_α photon.

Comparing energies of photons emitted between the K, L and M shells, we see that:

$$\frac{hc}{\lambda_{K_\beta}} = \frac{hc}{\lambda_{K_\alpha}} + \frac{hc}{\lambda_{L_\alpha}}$$

$$\frac{1}{0.139} = \frac{1}{0.154} + \frac{1}{\lambda_{L_\alpha}}$$

$$\lambda_{L\_\alpha} = 1.4 \text{ nm}$$



wavelength of L_α line = ... nm [2]

(c) The minimum wavelength λ_{min} observed in the continuous spectrum depends on the accelerating voltage *V* applied to the electrons. If the accelerating voltage is 30 kV, calculate λ_{min}.

Explain your working.

X-rays of wavelength λ_{min} are emitted if all of the electron's KE is converted into a single photon:
Energy of photon = KE of bombarding electron

$$\frac{hc}{\lambda_{min}} = q\Delta V$$

$$\frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{\lambda_{min}} = 1.6 \times 10^{-19} \times 30{,}000$$

$\lambda_{min} = 4.1 \times 10^{-11}$ = <u>0.041 nm</u>

λ_{min} = ... nm [2]

(d) Explain why knowledge of the X-ray spectra of elements like copper can be used to identify the existence of these atoms in materials.

When such atoms within materials are excited (by electron bombardment), they will emit X-rays with energies equal to the difference between the higher and lower energy levels. As these energy levels are specific to each element, so the energies and wavelengths of characteristic peaks are also unique to each element. Thus, x-ray analysis can be performed on an unknown target to determine the elements present. [1]

[Total: 10]

8 Wind energy is a renewable source of energy, harnessed from the kinetic energy of moving air. Since the late 1800s, windmills like the one shown in Fig. 8.1 have been used for milling grains.

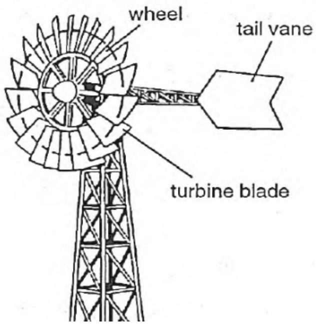


Fig. 8.1

Fig. 8.2 shows how the output power of these windmills varies with the overall diameter of the wheel for different wind speeds. The density of air is 1.3 kg m^{-3}.

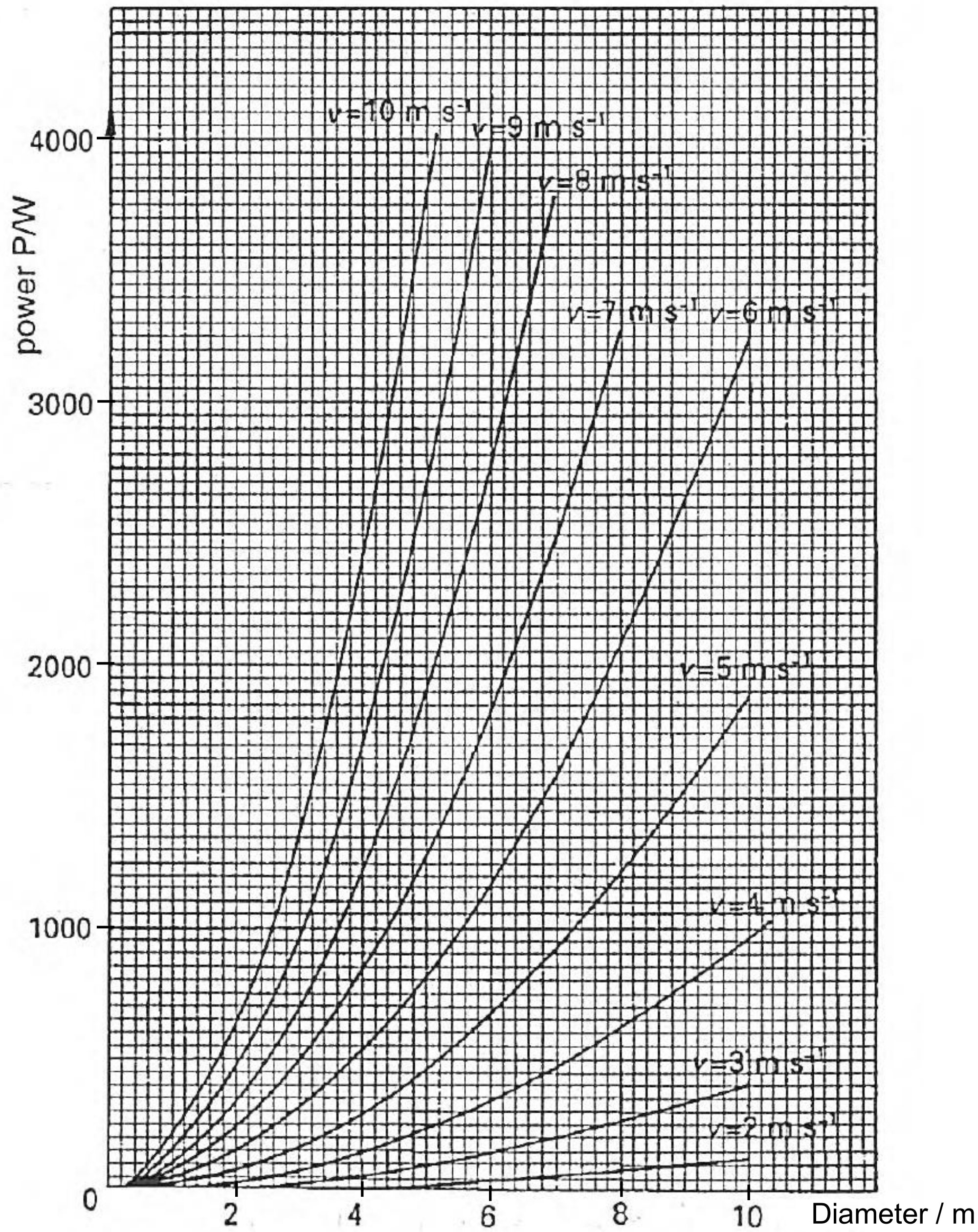


Fig. 8.2

Wind turbines are the modern evolutions of windmills. They have evolved from their multi-bladed predecessors to the modern 3-bladed version. Wind turbines have also increased in hub height and rotor diameter size in the last 45 years as shown in Fig. 8.3.

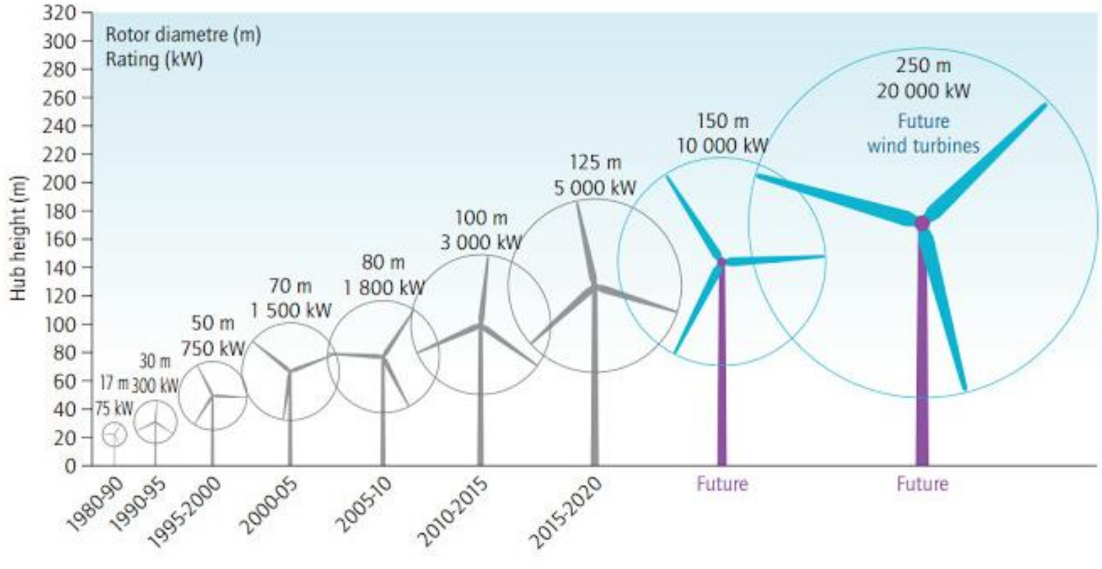


Fig. 8.3

Wind turbines have rotor hubs that can change the angle of attack of the rotor blades, which allows it to vary the amount of wind it catches. The nacelle houses a low-speed shaft that is connected to a gearbox which is in turn connected to a high-speed shaft before being connected to a generator. Parts of the wind turbine are shown in Fig. 8.4 below.

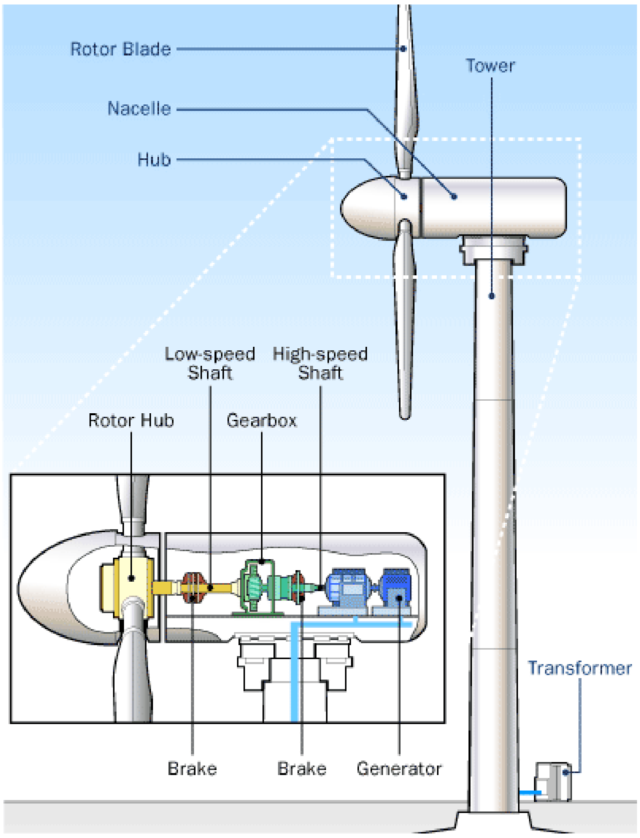


Fig. 8.4

The choice of location of wind turbines is an important factor to consider when building wind turbines. A table of average wind speed at various heights and locations are shown in Fig. 8.5.

Height above ground / m	Wind speed / m s^{-1}	
	On land	Offshore
20	2.43	3.52
50	3.86	4.51
75	4.11	5.96
100	5.29	7.27
125	6.43	9.51

Fig. 8.5

(a) The windmill is most efficient when the wheel and turbine faces the oncoming wind head-on. With reference to Fig. 8.1, explain how the tail vane works.

When the wheel is not facing the wind head-on, **a force acts on the tail vane**, due to the wind, which **provides a moment**, turning the wheel to face the wind head-on. [1]

(b) By considering the kinetic energy possessed by a cylindrical volume of air, prove that the input power P that can be harnessed by a windmill of cross-sectional area A is given by

$$P = \frac{1}{2}\rho A v^3,$$

where ρ is the density of air and v is the velocity of air. Explain your working.

Consider a cylindrical volume of air of cross-sectional area A.
The total power P possessed by this volume of air V is the total KE of the air in this volume divided by the time it takes for an air particle of velocity v to travel the length L of cylinder.

$$P = \frac{E}{t} = \frac{\frac{1}{2}(m)v^2}{t} \quad [1]$$

$$P = \frac{\frac{1}{2}(\rho V)v^2}{t} \quad \text{as } m = \rho V$$

$$P = \frac{\frac{1}{2}(\rho AL)v^2}{t} \quad \text{as the volume of a cylinder is } V = AL \quad [1]$$

$$P = \frac{1}{2}\rho A v^2 \frac{(L)}{t} = \frac{1}{2}\rho A v^3 \text{ (shown) as } v = \frac{(L)}{t} \quad [1]$$

[3]

(c) **(i)** For a windmill of diameter 9.0 m, state the power produced by the windmill when the wind speed is 6.0 m s^{-1}.

Power = 2650 W

power = ... W [1]

(ii) Calculate the efficiency of a windmill of diameter 9.0 m when the wind speed is 6.0 m s^{-1}.

Total input power = $P = \frac{1}{2}\rho A v^3 = 0.5(1.3)\pi\left(\frac{9.0}{2}\right)^2(6)^3 = 8931.9$ W [1]

From Fig. 8.1, a 9.0 m diameter windmill, wind speed of 6.0 m s^{-1}, P = 2650 W

Efficiency $= \frac{2650}{8931.9} \times 100\% = 29.67 = 30\%$ [1]

efficiency = ... % [2]

(iii) Suggest one reason for the loss in efficiency.

Any of the following: 1) Not all energy of air is captured, air still have KE to move past wheel 2) Resistive forces in the gears, 3) there are gaps in the wheel where air flows through

[1]

(d) **(i)** For the 3-bladed wind turbines built between 2010 to 2015, each typical rotor blade has an effective area of 120 m^2 that faces the wind head on. The dynamic wind pressure p is given by

$$p = \frac{1}{2}\rho v^2$$

where ρ is the density of air and v is the speed of air.

1. State the hub height of a typical wind turbine built on land between 2010 to 2015.

hub height = 100 m (Fig. 8.3) m [1]

2. By considering the wind speed at the hub height in your answer in **(d)(i)1.**, estimate the moments acting on the wind turbine taken about the base of the tower when built on land.

mtd 1

wind speed at hub height on land = 5.29 m s^{-1}

Moment $= F \times$ hub height h

$= p \times A \times h$

$= \frac{1}{2} \times \rho \times v^2 \times A \times h$

$= 0.5 \times 1.3 \times 5.29^2 \times (120 \times 3) \times 100$

$= 6.54 \times 10^5$ N m

moment = ... N m [2]

3. Hence suggest why modern wind turbines typically have only 3 blades even though a multi-bladed windmill ensures that more wind energy is harnessed.

Wind blowing on the rotors create a large moment about the base of the turbines. By having fewer blades, it reduces that chance of the wind turbines toppling over / falling / breaking.

[1]

(e) Explain how an increase in hub height and rotor diameter of wind turbines improves energy production.

Taller towers place the hub height in regions with higher wind speeds (Fig 8.6) [1] Larger rotors sweep a greater area, which, using $P = \frac{1}{2}\rho A v^3$, increases the input power and thus allows the turbine to produce more energy. [1]

[2]

(f) **(i)** Wind turbines typically spin at a rate of 10 to 20 rounds per minute. For a wind turbine with a rotor diameter of 250 m, calculate the speed at the tip of the blade if it were to spin at 30 rounds per minute.

Frequency f = 30 rounds per min = 30/60 = 0.50 Hz [1]

$v = r\omega = \frac{250}{2}(2\pi f) = 250\pi \times 0.50 = 393 \text{ m s}^{-1}$ [1]

speed = ... m s^{-1} [2]

(ii) Suggest why this rate of rotation is undesirable.

At 30 rounds per minute, the tip of the blades exceeds the speed of sound. OR This causes structural damage to the blades or produces noise pollution or causes a sonic boom.

[1]

(g) Explain, using the laws of electromagnetic induction, why there is a need to convert the rate of rotation of the shaft to a high rate before connecting to the generator.

Faraday's law states that the induced emf is proportional to the rate of change of magnetic flux linkage. The gearbox thus allows the generator to spin at higher rates, thus producing a larger emf. [1]

Since $P = V^2/R$, this means that more power is generated.[1]

[2]

[Total: 19]

End of Paper