NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 3

CANDIDATE NAME			
CLASS		TUTOR'S NAME	
CENTRE NUMBER	S	INDEX NUMBER	

PHYSICS — 9814/01

Paper 1

22 September 2021

3 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name and class 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 an HB pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Section A
Answer **all** questions.
You are advised to spend about 1 hour and 50 minutes on Section A.

Section B
Answer **two** questions only.
You are advised to spend about 35 minutes on each question in Section B.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
Section A	
1	
2	
3	
4	
5	
Section B	
6	
7	
8	
Total	

This document consists of **28** printed pages.

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_o	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
		=	$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} J K^{-1}
gravitational constant	G	=	6.67×10^{-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	=	$u^2 + 2as$
moment of inertia of rod through one end	I	=	$\frac{1}{3}ML^2$
moment of inertia of hollow cylinder through axis	I	=	$\frac{1}{2}M(r_1^2 + r_2^2)$
moment of inertia of solid sphere through centre	I	=	$\frac{2}{5}MR^2$
moment of inertia of hollow sphere through centre	I	=	$\frac{2}{3}MR^2$
work done on/by gas	W	=	$p\Delta V$
hydrostatic pressure	p	=	ρgh
gravitational potential	ϕ	=	$-Gm/r$
Kepler's third law of planetary motion	T^2	=	$\frac{4\pi^2 a^3}{GM}$
temperature	T/K	=	T/°C + 273.15

pressure of an ideal gas	p	=	$\frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas 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	=	$v_0 \cos \omega t$
		=	$\pm\omega\sqrt{\left(x_0^2 - x^2\right)}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
capacitors in series	$1/C$	=	$1/C_1 + 1/C_2 + \ldots$
capacitors in parallel	C	=	$C_1 + C_2 + \ldots$
energy in a capacitor	U	=	$\frac{1}{2}CV^2$
electric potential	V	=	$\frac{Q}{4\pi\varepsilon_0 r}$
electric field strength due to a long straight wire	E	=	$\frac{\lambda}{2\pi\varepsilon_0 r}$
electric field strength due to a large sheet	E	=	$\frac{\sigma}{2\varepsilon_0}$
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	=	$\mu_0 nI$
energy in an inductor	U	=	$\frac{1}{2}LI^2$
RL series circuit	τ	=	$\frac{L}{R}$
RLC series circuits (underdamped)	ω	=	$\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$
radioactive decay	x	=	$x_0 e^{-\lambda t}$
decay constant	λ	=	$\frac{\ln 2}{t_{\frac{1}{2}}}$

Section A

Answer **all** questions in this section.

You are advised to spend about 1 hour 50 minutes on this section.

1 **(a)** Explain why the center of mass frame of reference is also the zero momentum frame of reference.

....

....

.... [1]

(b) A ball of mass m to the right with velocity *u* and make an elastic collision with a stationary ball of mass m_2 as shown in Fig 1.1

Fig. 1.1

The two balls is scattered by a certain angle after the collision as shown in Fig. 1.2. The ball with mass m_1 is scattered by an angle θ_1 with a velocity of v_1 .

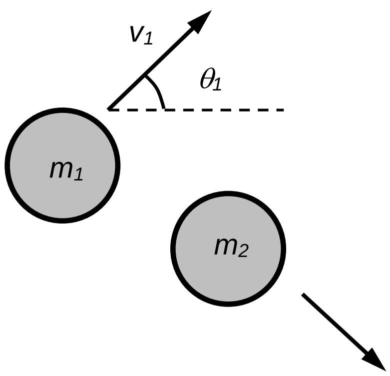

Fig. 1.2

(i) Show the scatter angle θ_1 of the ball with mass m_1 in the laboratory frame of reference is related to the new scatter angle α in the center of mass frame of reference by the following relation

$$\tan\theta_1 = \frac{\sin\alpha}{\cos\alpha + \frac{v_{CM}}{u'}}$$

where u' is the initial velocity of ball A in the center of mass frame of reference.

[5]

(ii) If the two balls have equal mass, use the relationship in **(b)(i)** to determine the value of α when $\theta_1 = 45^o$

angle α = ... [3]

(iii) Explain why the value α is always less than the value of θ.

....

....

....[2]

[Total: 11]

2 **(a)** A solid sphere of radius R and mass M is released from rest at the top of an inclined plane as shown in Fig. 2.1. The inclined make an angle of θ with the horizontal. The coefficient of friction is μ. Assume the sphere rolls down the slope without slipping.

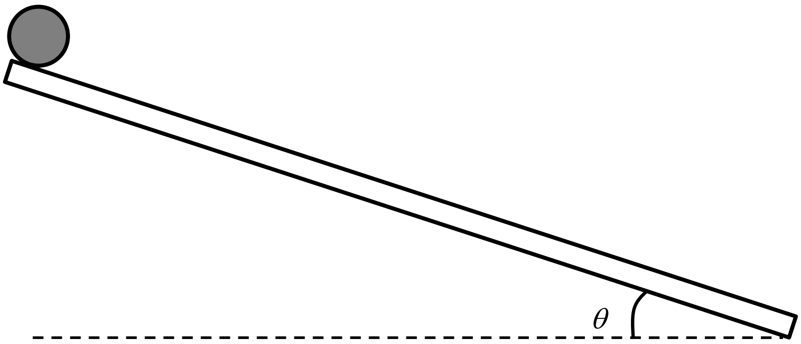

Fig. 2.1

(i) Determine the linear acceleration of the sphere in terms g and θ.

linear acceleration = ... [3]

(ii) Determine an expression for the angular acceleration of the sphere.

angular acceleration = ... [2]

(b) Explain why when the angle of the slope is increased, there is a critical angle which the sphere will roll and slips down the slope if the angle of the slope is more than this value.

....

....

....

.... [2]

(c) Determine this critical angle given that the value of coefficient of friction μ= 0.30.

critical angle = ... [3]

[Total: 10]

3 A plano-cave lens having refractive index of 1.50 is placed on a flat glass plate, as shown in Fig. 3.1.

Its curved surface, with radius of curvature 8.0 m, is on the bottom. The lens is illuminated from above with yellow sodium light of wavelength 589 nm, and a series of concentric bright and dark rings is observed by reflection. The interference pattern has a dark spot at the center, surrounded by 50 dark rings, of which the largest is at the outer edge of the lens.

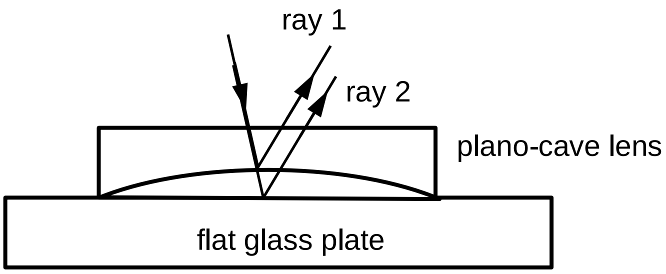

Fig. 3.1

(a) By considering the paths of ray 1 and ray 2, explain how the series of bright and dark ring is formed.

....

....

....

.... [2]

(b) Explain why there is a phase change of 180^{o} for ray 2 when it is incident on the flat glass plate based on the evidence that the position which the path difference between ray 1 and ray 2 is zero correspond to a dark ring.

....

....

....

.... [2]

(c) Determine the thickness of the air layer at the center of the interference pattern.

thickness = ... m [3]

(c) Calculate the radius of the outermost ring.

radius = ... m [2]

(d) **(i)** A second yellow light of wavelength 589.6 nm is used instead. Determine whether the number of dark rings will still be 50.

[2]

(ii) Suggest why the intensity of the dark ring near the center if higher compared those near the edge.

....

....

....[1]

[Total: 12]

4 **(a)** An elastic string which of force constant k is attached between two fixed points X and Y. The distance between X and Y is L and the string is initially unstretched.

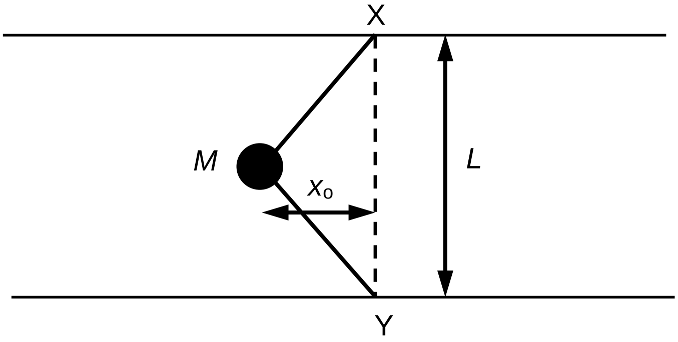

Fig. 4.1

A sphere of mass m is connected to the midpoint of the string. The sphere is then pulled a small distance x_o, perpendicular to the string and then released as shown in Fig 4.1.

(i) Determine an expression for the initial acceleration for the sphere.

(Hint: for $z \ll 1$, $(1 + z)^n \approx 1 + nz$)

acceleration = ... [5]

(ii) Based on the expression, explain why the motion of the sphere is not simple harmonic.

....

....

....[2]

(iii) Describe a method to determine the period theoretically of the oscillation with doing the detailed mathematical calculation.

....

....

....[2]

[Total: 9]

5 The Spallation Neutron Source (SNS), based in the UK at the Rutherford Appleton Laboratories (RAL) in Oxfordshire, is a world-renowned facility for probing matter on an atomic scale using neutron beams.

Electromagnetic radiation from infrared, visible and ultraviolet, through to X-rays and gamma radiation, is a familiar probe for investigating matter. Rutherford's famous experiments used alpha particles as probes. All these interact with matter through electromagnetic forces.

Neutrons have a comparatively large mass, neutral charge, and a small but significant magnetic dipole moment and nuclear spin. They penetrate matter and interact with it through the strong nuclear force as well as magnetism.

Fig. 5.1 show the properties of neutons

Mass	1.675×10^{-27} kg
Quark content	udd(one up quark, two down quarks)
Charge	$+\frac{2}{3}e-\frac{1}{3}e-\frac{1}{3}e=0$
Magnetic dipole moment	$-1.913\mu_N$
$1\ \mu_N = 5.05 \times 10^{-27}$ J T^{-1}	

Fig. 5.1

(a) **(i)** With reference to the charge, explain why the quark content for a neutron is one up quark and two down quark.

....

....

.... [1]

(ii) Suggest a possible quark content for a proton. Explain your choice of answer.

....

....

.... [2]

(b) **(i)** Calculate the magnetic dipole moment of a neutron. Include appropriate units.

magnetic dipole moment = ... [2]

(ii) Explain the significant of the negative sign for the magnetic dipole moment for the neutron on the direction of spin of the neutron relative to the direction of the magnetic field. You may draw a sketch .

....

....

....[2]

(iii) Suggest a method to accelerate neutrons.

....

....

....[2]

Neutrons are baryons (the class of 'heavy' subatomic particles that also includes protons and are held together in the nucleus by the strong nuclear force. Each is composed of three quarks bound together by glutons. Neutrons decays by the weak interaction, undergoing beta-minus decay to produce a proton, electron and antineutrino. Within a nucleus, neutrons can remains stable for a long time but free neutrons decay with half-life of 10.3 min.

The stability of neutrons within nuclei is explained by the energies which would be involved in the decay of a neutron which is spin paired with a proton. Although the correct explanation is not in terms of electrostatic force it is worthwhile to look at this force for a deuteron.

A deuteron is a proton and neutron spinning about their center of mass. The proton and neutron are held together by the spin pairing force and the strong nuclear force.

The potential energy U of that arrangement can be determined as follow:

$$U = \frac{ke^2}{s}$$

where k is constant with value = 9×10^9 N m^2 C^2, e is the charge of a proton and s is the nucleon separation.

Neutrons beams can be moderated to match the distances and energies that are characteristic of matter. These so-called thermal and cold neutrons have energies in the range of 1- 100 meV, which is comparable to lattice vibrations in the range 0.1 mm to 0.5 mm similar to interatomic distances.

Fig. 5.2 shows the approximate energies and wavelength of neutrons

Neutrons defined as….	Temperature T/K	Kinetic energy, Ek / meV	De Broglie wavelength λ/nm
Cold	20 - 290	2 -25	0.7 – 0.2
Thermal	290	25	0.2
Hot (epithermal)		25 -400	

Fig. 5.2

(c) (i) Fill in the blanks in Fig. 5.2 with appropriate range of values for the temperature and De Broglie wavelength.

[3]

(ii) Show that the de Broglie wavelength λ of neutrons at thermodynamics temperature *T* is related as follow:

$$\lambda = \frac{h}{\sqrt{2mkT}}$$

where m is the mass of the neutron and k is the Boltzmann constant

[3]

(d) **(i)** Estimate a suitable value for the nucleon separation *s*.

nucleon separation = ... m [1]

(ii) Hence calculate the potential energy *U* of the deuteron.

U = ... MeV [2]

[Total: 18]

Section B

Answer **two** questions from this section

You are advised to spend about 35 minutes on each question.

6 **(a)** Show, from first principles, the moment of inertia of a disk I of mass *M* and radius *R* about the central axis is given by :

$$I = \frac{1}{2}MR^2$$

[4]

(b) The turntable of radius 25 cm for a clay pottery making machine is shown in Fig. 6.1. The mass of the turntable is 20 kg . The minimum revolution to make the clay pottery using the turntable is 240 revolutions per minute.

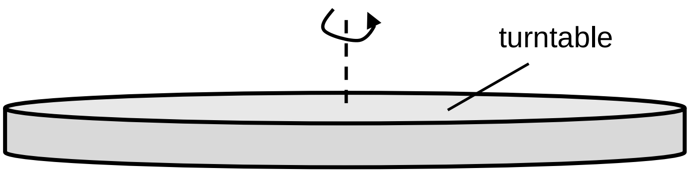

Fig. 6.1

(i) Determine the minimum power needed to accelerate the turntable to 240 r.p.m given the torque of the motor is 14000 Nm.

minimum power = ... W [3]

(ii) Suggest why the actual power required will be more than the one calculated in **(a)(i)**.

....

....

....[2]

(c) The power is then switched off and the angular speed of the turntable is assumed to remain constant. A clay of mass 1.0 kg rolled into the shape of a small sphere is released from rest from a small height above the turntable as shown in Fig. 6.2. The clay sphere is 15 cm from the axis of rotation of the turntable.

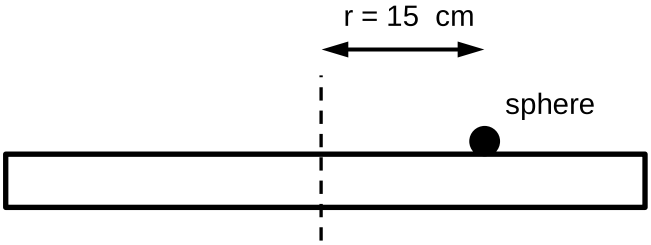

Fig. 6.2

(i) Use conservation of angular momentum to determine the new angular speed of the turntable after the spherical clay move together with the turntable. A stopper is used to prevent the sphere from sliding on the turntable.

new angular speed = ... [3]

(ii) Use Newton's law of rotation motion to explain why the angular speed of the turntable decrease after the spherical clay landed on the turntable.

....

....

....

....

....[3]

(iii) The angular speed of the turntable is then gradually increased from zero with the stopper removed . The coefficient of static friction μ is 0.40. Determine the angular speed of the turntable when the friction force between the clay sphere reached the limiting value.

angular speed = ... [2]

(iv) Suggest why the clay sphere will start to slide before the turntable reached the value calculated in **(b)(iii).**

....

....

....[1]

(v) In another situation, a clay sphere of mass 2.0 kg is released at the axis of rotation. After some time, the shape of the spherical clay flatten to become a 'disk' shape. Give an explanation for this phenomenon.

....

....

....[2]

[Total: 20]

7 (a) Suggest the Gauss's law for the gravitational field.

....

....

.... [1]

(b) A point mass of mass m is located at a distance r from the centre of a thin spherical shell of mass *M* as shown in Fig. 7.1. The radius of the spherical shell is *R* and point O is the centre of the sphere.

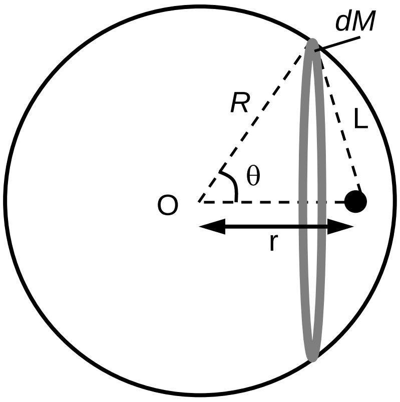

Fig. 7.1

(i) By considering a loop of mass *dM* around the spherical shell , show that potential energy of a point mass at any point inside the spherical shell is given by

$$U = -\frac{GmM}{R}$$

[4]

(ii) By making reference to the answer in **(b)(i)** explain why the gravitational field strength located anywhere inside the spherical shell is always zero.

....

....

....[1]

(iii) Using the statement in **(b)(ii)** , show the gravitational field strength *g* at a distance r from the centre of Earth is:

$$g = \frac{4}{3}\pi G \rho r$$

where $0 < r < R_E$. R_E is the radius of Earth and *p* is the density of Earth. Explain your working.

[2]

(iv) Use the Gauss's law for gravitational field to show the same expression in **(iii)**

[3]

(iv) Suggest a situation which the Earth's density is not uniform but the value of g is still the same at equal distance from the centre of the Earth.

....

....

....[2]

(c) Suppose a hole is drilled through the centre of the Earth and a rock is released from rest.

(i) Explain why the rock will perform a simple harmonic motion.

....

....

....

....

....[3]

(ii) Determine the period of oscillation of this rock . The radius of Earth is 6400 km and assumed to have a uniform density equal average density.

period = ... m [2]

(d) A hypothetical planet has a radius of R' = 5400 km and density 4400 kg m^{-3} with a empty cavity of radius ½ R' on side of the planet as shown in Fig. 7.2.

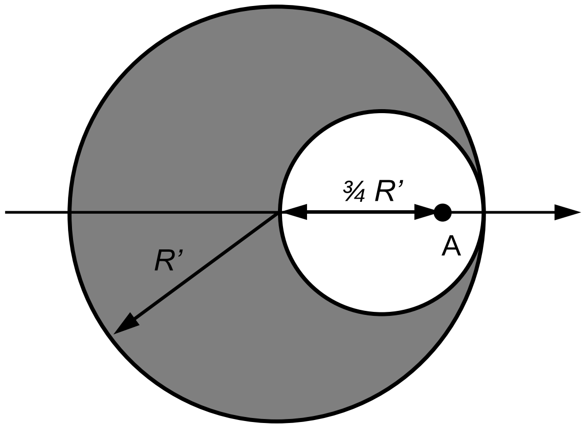

Fig. 7.2

Use the expression in **(b)(iii)** to determine the gravitation field strength at point A.

[2]

[Total: 20]

8 **(a)** Determine the total capacitance for the following infinite network of capacitors.

(i) Fig. 8.1A shows an infinite network of capacitors each with capacitance C = 1.0 μF. The number of capacitors is doubled each time a row of capacitors is added to it.

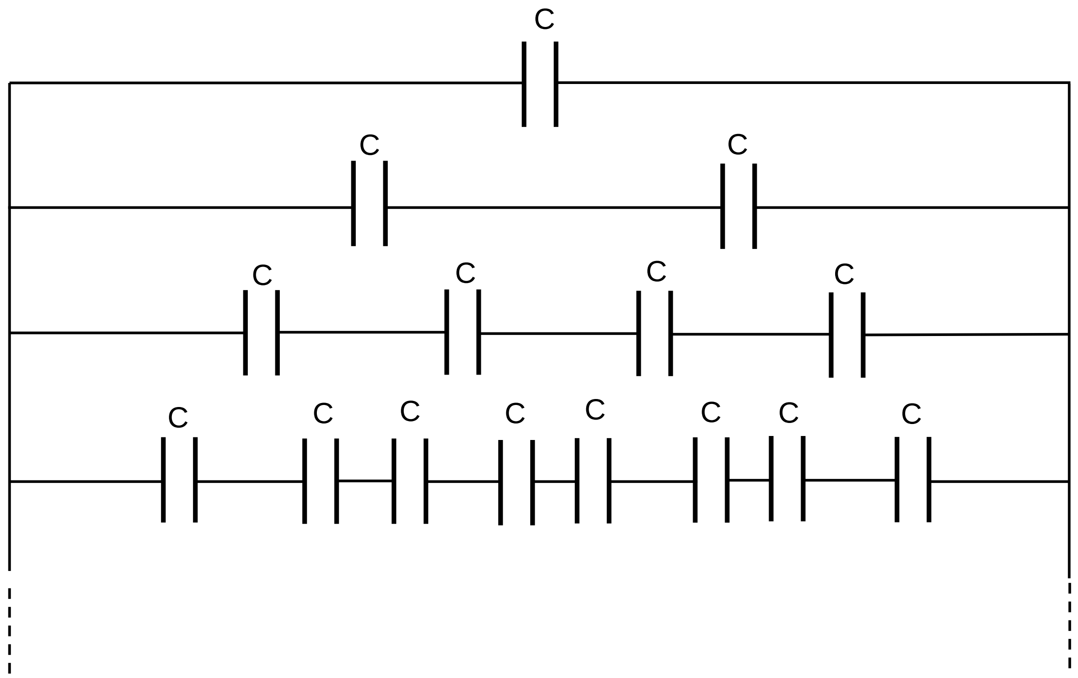

Fig. 8.1A

total capacitance = ... μF [3]

(ii) Fig. 8.1B shows an infinite network of capacitors. Two identical capacitors is added to each row with the capacitance increased by 3 times compared to the previous one. A capacitor of capacitance 1.0 μF is also added to each row.

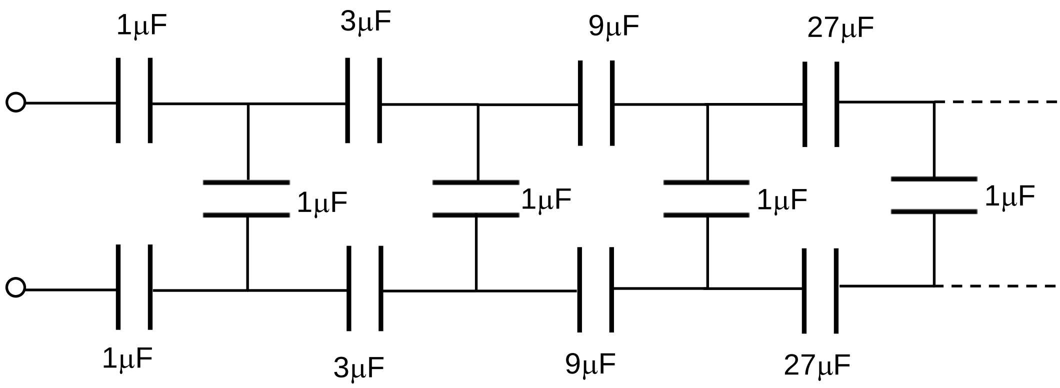

Fig. 8.1B

total capacitance = ... μF [3]

(b) An infinite network of capacitor each of capacitance C is shown in Fig. 8.2. The equivalent capacitance for the infinite capacitor is assumed to be C_o.

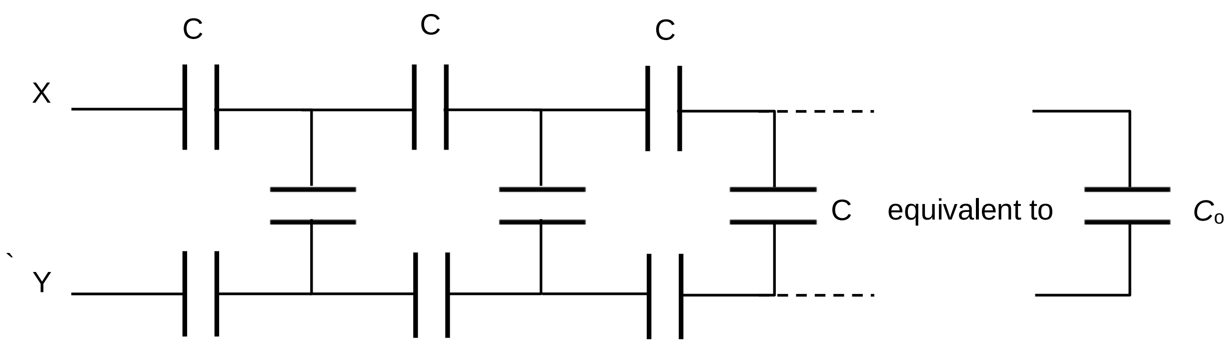

Fig. 8.2

An extra segment of 3 capacitors each of capacitance *C* is added to the left hand side of the network . The combination of the 3 capacitor and the infinite network is equivalent to the total capacitance shown in Fig.8.3.

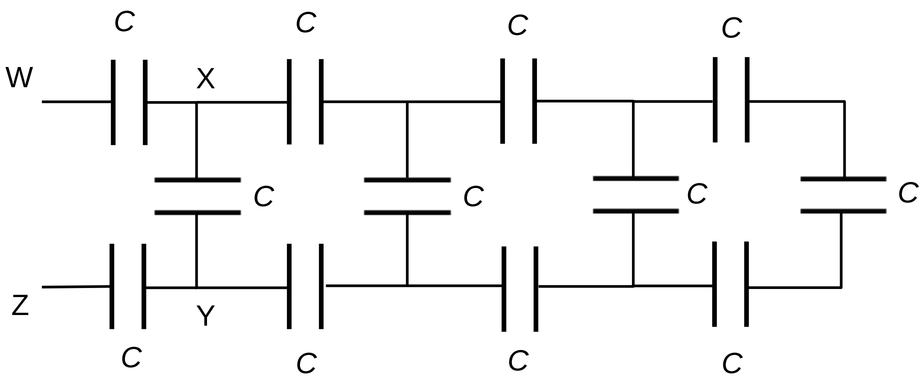

Fig. 8.3

equivalent to

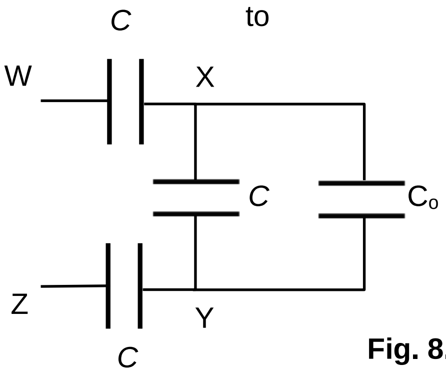

Fig. 8.4

(i) For Fig. 8.4, determine in terms of C and C_o the total capacitance across WZ.

total capacitance = ... [2]

(ii) Hence show that $Co = = \frac{C(\sqrt{3}-1)}{2}$

[3]

(iii) The infinite long network of capacitors is then connected to a 12 V supply in series with a resistor of 10 kΩ. Determine the amount of charge stored in the capacitor just after 0.02 seconds. Assume the capacitor is initially uncharged when time t = 0.

charged stored in capacitor = ... [4]

(iv) Determine the total energy stored in all the capacitors when t = 0.02 s.

total energy stored in capacitors = ... [2]

(v) Determine the current through the 10 kΩ resistor at the same instant.

current = ... A [2]

(vi) Suggest why the actual time taken for the current through the resistor to reach the value calculated in **(iv)** is longer for the infinite network of capacitors.

....

....

....[1]

[Total: 20]