Section A: Guided Short-Answer [3 marks each]

You must show your reasoning to gain the full three marks. Two marks are allocated for reasoning, one mark for making the correct choice (T or F for a True/False question; one of a, b, c, d, e for a multichoice question. A correctly chosen option without supporting working cann earn no more than one mark.

1. Shuttle astronauts orbiting the Earth report weightless conditions because they are so far from Earth that its gravitational field is essentially zero. True or false?

2. If work *W* is done to extend a spring a distance *x* from equilibrium, then *additional* work 2W will be required to increase the extension from x to 2x. True or false?

3. The time-constant of an *RC* circuit is the time needed to completely discharge the capacitor. True or false?

4. A bar magnet is a magnetic dipole (contains both north and south poles). If a bar magnet is snapped in half, each fragment will be a magnetic monopole. True or false?

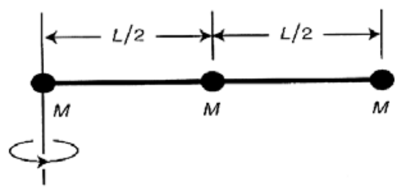
5. There can be an induced emf at an instant when the magnetic flux through the circuit is zero. True or false?

6. A pendulum bob of weight 2 N is held at an angle θ from the vertical by a horizontal force *F* as shown. The tension in the string supporting the pendulum bob (in newtons) is:

(a) $2 / \cos\theta$
(b) $3 \sin\theta + 2$
(c) $\sqrt{13}$
(d) None of these.

7. Three identical objects, each of mass *M*, are fastened to a massless rod of length *L* as shown. Assuming each object can be treated as a point mass, the inertia about one end of this array is:

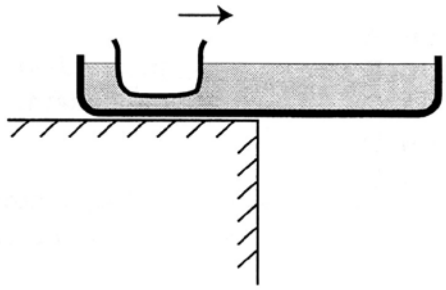
(a) M L2/2
(b) M L2
(c) 3M L~/2
(d) SM L`/4
(e) 3M L2



Question B1. Floating, Falling, and Log-log Skills

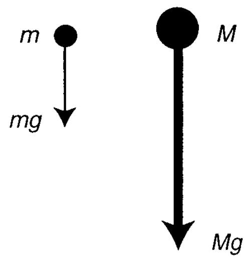
[3 marks]

(a) A young visitor becomes distracted by the idea of floatation while washing the dishes. She pours water into a large rectangular dish, then carefully balances the dish at the edge of the kitchen bench, so that half of the dish teeters unsupported above the floor. She slowly lowers a china sugar-bowl into the water so that it floats like a boat, then, with a gentle nudge of her finger, launches the bowl towards the edge. What does, or does not, happen as the bowl crosses the edge of the bench? Justify your prediction.



[3 marks]

(b) *In the absence of air resistance, till objects fall at the same rate.* A Form-6 student is bothered by this statement, and discusses it with you. He draws a diagram showing a heavy object alongside a light object, both of which are to be released at the same instant. He explains, "It's obvious that the heavy object experiences the larger gravitational force from Earth. So why doesn't the heavy object fall faster than the light object, and so hit the ground first?" What explanation do you give to the student to resolve his difficulty?



(c) Your teacher asks you to assist with a demonstration of free-fall acceleration for the educational benefit of fifth-form science students who will be called to assemble for the occasion in the school hall. Two strings of lead weights (fishing sinkers) are to be suspended from the ceiling. For the first string, the weights are equally-spaced as shown on the diagram and in the table on the next page. (For the second string, the positions of the weights have yet to be determined.)

When the teacher gives the word, you are to release the string from the ceiling, allowing the line of sinkers to come crashing to the floor.

Question B2. Plants, Plumb-lines, Candles & Planes

(a) The photograph shows what happens when plants (jonquils) grow on a rotating platform. The rotation rate is 65.2 rev/min (the platform has been stopped for the photo).

Since plants are programmed to grow vertically `up', this demonstration provides convincing evidence that, in a rotating environment, the directions `vertical' and `horizontal' change. We can understand this plant behaviour by assuming that a plant determines which way is `up' from the contact forces it experiences from the soil. There is an *upwards* soil force $N = mg$ to balance gravity, and an unbalanced *inwards* soil force $F_{in} = mv^2/r$ to provide the centripetal acceleration required for circular motion. The `up' direction is then given by the vector sum $N + F_{in}$.

[3 marks]

(i) Draw a vector diagram showing these soil contact forces for a seedling at radial distance r from the rotation axis. Show that the vector addition of $N + F_{in}$ gives a resultant which makes an inward angle θ with respect to true vertical given by

$$\tan\theta = \frac{\omega^2 r}{g}$$

Question B3. Statics; SHM (tides); Satellites

(a) A uniform beam, freely hinged at the wall, is supported by a wire 9 m from the wall at an angle of 37°. The mass of the beam is 50 kg, and its length is 14 m. The mass held at the end is 100 kg.

[1 mark]

(i) Draw a free-body diagram of the beam showing all of the forces acting on it.

[I mark]

(ii) We wish to determine the tension T_{in} the wire. Explain why it would be a sensible strategy to take moments about the hinge pin of the beam.

[3 marks]

(iii) By taking moments about the hinge (or otherwise), determine the tension T in the wire. Show all working.

(b) The following figure (next page), from data provided by Ocean Fun Publishing and NZ MetService, shows the height of the sea surface (in metres), as a function of time, for two New Zealand locations. To good approximation, the tidal oscillation can be treated as SHM.

In your answers to these questions, show your working and round off your answers to two significant figures.

Question B7. Waves and Interference

(a) The diagram shows a Young's double-slit set up. S_1 and S_2 represent the coherent sources of light emitted by the slits. The bright fringes (interference maxima) are located at angles θ given by

$$d\sin\theta = m\lambda$$

T
d

S2

distant
screen

[2 marks]

(i) Give a careful physical interpretation of this equation. Make sure you explain the origin and significance of the $d\sin\theta$ term. Use a diagram to aid your explanation.

The sources are separated by a distance equal to 100 times the wavelength of the light passing through the slits.

[1 mark]

(ii) What is the angular separation in radians between the central maximum and an adjacent maximum?

[2 marks]

(iii) What is the distance between these maxima on a screen 50.0 cm from the slits? [

1 mark]

(b) The $d\sin\theta = m\lambda$ interference equation also works for a diffraction grating, where d is now the distance between adjacent rulings on the grating. If a grating is marked `600 lines per mm', what is the value of d for this grating?

(c) There is a rather similar equation which applies for *reflection* gratings in which the diffraction patterns are generated by reflected light, rather than by transmitted light. For a reflection grating, interference maxima will occur when the incoming and outgoing angles are related as:

$$d\,(\cos\theta_{in} - \cos\theta_{out}) = m\lambda$$

$m = +2$ $m = +1$

where the angles are measured from the plane of the grating.

$m = -1$

Question B8. Nuclear & Atomic Physics; Order-of-Magnitude Estimation

[1 mark]

(a) The following extract comes from a recent short story by Brian Aldiss. What is wrong with the author's science?

> Other alarming news was ignored for the time being; that physical constants had changed meant little to the man in the street. As startled physicists were soon to prove, the energy equation was now
>
> $$E = mc^{2.7713}$$
>
> From now on, a great deal more matter would be needed to produce one joule of energy. Nuclear power plants started to go out of business.

For the following questions on nuclear physics, you will need to work to 7 significant figures. Here are the physical constants which may be useful:

$c = 2.997\,925 \times 10^8$ m/s
$e = 1.602\,177 \times 10^{-19}$ C

[3 marks]

(b) The unified mass unit (u) is defined to be $^1/_{12}$ of the mass of 1 atom of carbon-12:

$1 \text{ u} = 1.66054 \times 10^{-27}$ kg

Show that 1 u is equivalent to an energy of 931.5 MeV.

(c) In the Sun, hydrogen nuclei (protons) fuse to form helium nuclei:

$$4\,{}^1_1H \rightarrow {}^4_2He + 2X + (energy)$$

[1 mark]

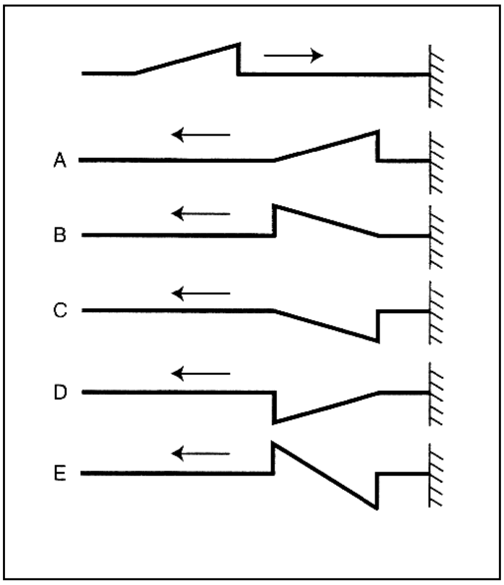
(i) What is X in this equation?

[3 marks]

(ii) Given the following mass data, determine how much energy is released in the fusion reaction.

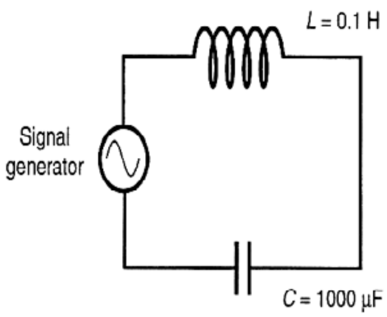
mass of proton:	1.007276 u
mass of helium nucleus:	4.00151 u
mass of X:	0.000549 u

8. The pulse shown is moving in the string toward a fixed end at the wall. After reflection at the wall, which figure correctly represents the pulse?



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

9. A signal generator, set to generate a sinewave voltage of frequency 50 Hz, is connected to a series LC circuit for which $1/(2\pi\sqrt{LC})$ = 16 Hz. The current in the circuit will oscillate at a frequency of:



(a) 50 Hz
(b) 16 Hz
(c) between 16 and 50 Hz
(d) less than 16 Hz
(e) zero (i.e., no oscillations)

10. A radioactive substance in the laboratory has a half-life of 8 hours. At noon today, a Geiger counter reads 480 counts per minute above background. At midnight tonight, the counter should read about:

(a) 480 counts/min
(b) 240 counts/min
(c) 210 counts/min
(d) 170 counts/min
(e) 120 counts/min

Sinker	Height (m)
A	3.20
B	2.20
C	1.20
D	0.20

A microphone and oscilloscope have been set up to monitor the volley of crashes as each weight hits the floor. The oscilloscope is set for a slow sweep-speed to enable display of a graph of `loudness' (y-axis) versus time (x-axis).

[3 marks]

(i) Calculate the time-of-flight *(t)* for each of the four sinkers. Explain why equally-spaced weights would *not* be expected to produce crashes which are equally spaced in time.

[1 mark]

(ii) Sketch a diagram showing the expected oscilloscope display. Assume that the display starts sweeping at the instant you release the line of sinkers, and that each crash shows up as a momentary `blip' whose amplitude is proportional to the sound intensity.

[3 marks]

(iii) Using log-log paper, use your data from part (i) to plot a graph of time-of-flight t (on y-axis) versus height *h* (on x-axis). Draw the line of best fit.

[2 marks]

(iv) For the modified sinker line, we want to rearrange the sinkers so that the time-interval between crashes is constant. Keeping the positions of the top and bottom (A and D) sinkers unchanged, how would you alter the positions of the middle pair (B and C) to give equally-spaced crashes? [**Either**: *For 1 mark:* Sketch a diagram showing the approximate sinker arrangement; ***or*** *for 2 marks:* Do the calculations (or use your graph) to determine the precise locations for sinkers B and C.]

[1 mark]

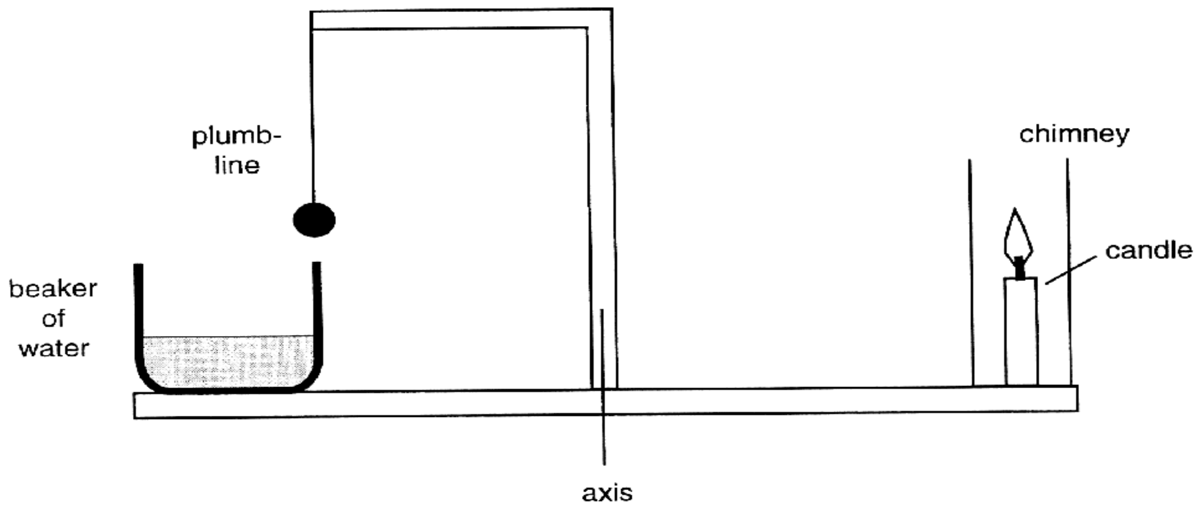
(ii) Convert the rotation rate of 65.2 rev/min to rad/s.

[5 marks]

(iii) A graph of tanθ (y-axis) versus r (x-axis) should give a straight line of slope ω^2/g. Using the following measurements, plot a suitable graph and draw in the best-fit straight line. Measure its gradient, and compare with the predicted value.

r (cm)	Tilt, θ
0	0
4.0	10°
6.5	15°
13.3	33°
22.5	46°

Standing on Earth, we take the plumb-line direction as vertical, and a water surface as horizontal. Suppose we place a beaker of water, a plumb-line, and a candle (protected from drafts by a glass chimney) on board the rotatable platform:



(iv) Sketch a diagram showing how the plumb-line, water surface, and candle flame will orient themselves when the platform is rotating about its axis. Give an explanation for *all* of your three predictions.

[2 marks]

(b) Using a small plumb-line and a protractor, it is possible for a passenger on board a jet-aircraft to measure the maximum acceleration during take-off. Explain how this can be done.

Tauranga

Height (m)	Time
1.7	1:59
0.3	8:10
1.6	14:26
0.4	20:26

Tauranga

3 6 9 12 15 18 21 24

Raglan

Raglan

Height (m)	Time
2.8	4:52
1.0	11:11
2.7	17:25
1.1	23:41

Time today: Hours since midnight

[2 marks]

(i) Calculate the period of oscillation, in hour:min, for the lower (Raglan) trace.

[2 marks]

(ii) Calculate the amplitude of the lower trace.

[2 marks]

(iii) Calculate the phase difference, in degrees, of the Raglan trace relative to the Tauranga trace.

[2 marks]

(iv) Show that the maximum speed with which the sea surface changes height, for the Raglan trace, is about 0.45 m/hr.

[2 marks]

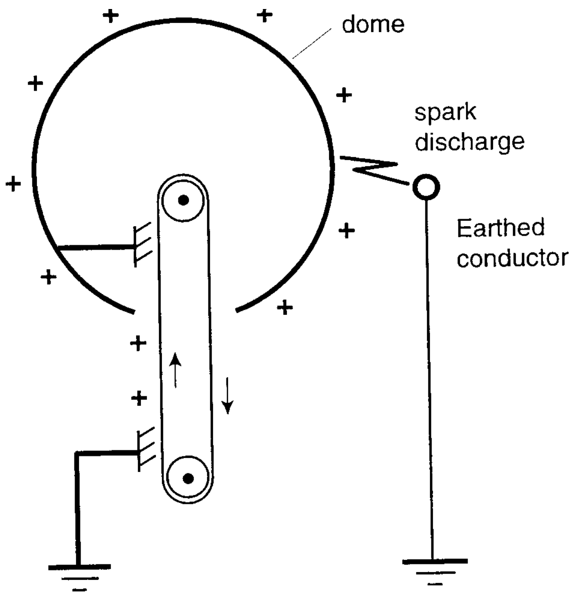
(c) Science fiction is often entertaining, but sometimes portrays incorrect science. Identify the science error in the following excerpt from a SF movie.

Captain:	Where is the alien spacecraft now?
Advisor:	They have parked their craft in geostationary orbit over London.

(c) The electrostatic charging of persons can be achieved using a Van de Graaff generator. This device uses friction to charge a rotating rubber belt; the belt carries the charge up to a metal brush inside a hollow spherical conductor. The sphere accumulates charge until the electric field surrounding the sphere exceeds the dielectric strength (breakdown voltage) of air. At this point, the air ionizes (becomes conducting), and we see a spark as the sphere rapidly discharges.

For New Zealand conditions, the maximum electric field in air is

$E_{max} \approx 10^4$ V/cm.



An earthed conductor is placed 1 cm from the Van de Graaff sphere, and a momentary 1-cm-long spark is generated at 1-second intervals.

[3 marks]

(i) Sketch a labelled graph showing how the potential (in volts) on the sphere varies with time. Would you expect the `charging-up' portion of the graph to be linear or curved? Explain. [Assume that the sphere completely discharges with each spark.]

[2 marks]

(ii) The capacitance of an isolated sphere of radius R is given by

$$C = 4\pi\varepsilon_0 R.$$

Calculate the maximum charge Q_{max} carried by the sphere. Take the radius as R = 20 cm.

[1 mark]

(iii) If each spark lasts 0.05 s, what is the current carried in the spark? [Note: If you could not solve part (ii), say so, and use Q_{max} = 0.6 μC here.]

[1 mark]

(iv) How much enemy is stored in the sphere immediately prior to a spark discharge?

Question B4. Gravity and Electricity

(a) Two (substantial) persons A and B, each of mass 100 kg, are situated such that their respective centres of mass are separated by a distance of 1 m.

[1 mark]

(i) Using Newton's law of gravitation $F_{grav} = Gm_1m_2/r^2$, calculate the force of attraction that person-B exerts on person-A. Assume that each person can be treated as a point(!) mass.

[2 marks]

(ii) If this attractive force were the only force acting on person-A, with what acceleration would person-A accelerate towards person-B? Would this acceleration remain constant? Explain. (Assume they don't collide.)

(b) The two persons of part (a) are standing on (frictionless) insulating platforms. Person-A carries a charge (distributed over his body) of $q_1 = +2\ \mu C$, while person-B carries a charge of $q_2 = -2\ \mu C$. Assume that each person can now be treated as a point charge, and that the distance between this pair of point charges is 1 m.

[1 mark]

(i) Using Coulomb's law of electric force $Felec = kq_1q_2/r^2$ calculate the electric force which acts on person-A due to the charge on person-B. Is this force attractive or repulsive? [**Note**: The value for Coulomb's constant is listed on the front cover.]

[2 marks]

(ii) Calculate the ratio $F_{elec} : F_{grav}$ Comment.

[2 marks]

(iii) Despite your answer in part (b)(ii), it seems that in calculations involving the motions of satellites, planets, and celestial bodies, we consider only gravitational forces and ignore the electrostatic forces. Why is this a reasonable thing to do?

Question B6. Magnetic Force, Magnetic Flux, and Induced emf

[2 marks]

(a) Define what is meant by *magnetic flux* ΦB.

[3 marks]

(b) Given a flexible loop of wire, a large permanent magnet, and a voltmeter, describe *three* methods by which you could demonstrate that a changing magnetic flux induces an emf. Use diagrams to aid your explanations.

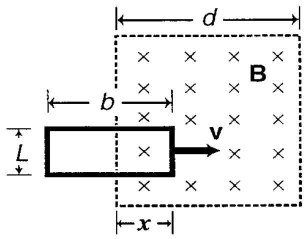
(d) The diagram shows a rectangular loop of wire of width L and length b being pulled at constant speed v through a region of width d in which a uniform magnetic field **B**, directed into the page, is produced by an electromagnet. Let L = 4 cm, b = 10 cm, d = 15 cm, B = 2.0 T, and v = 1.0 m/s. The resistance of the loop is R =1.6 Q.

[1 mark]

(i) Write down an expression, in terms of x, for the magnetic flux OB through the loop when it is in the position shown in the diagram.

[1 mark]

(ii) Give a numerical value for OB when the loop is entirely within the field (i.e., when 10 cm ≤ x ≤ 15 cm).



[3 marks]

(iii) What is the size of the induced emf as the loop enters the field? W and direction of the resulting current in the loop?

[1 mark]

(iv) What is the size of the induced emf when the loop is entirely with your answer.

(d) An electron, travelling at v = 3.0 x 10^6 m/s, enters a uniform magnetic field B of magnitude 2.0 T whose direction is into the plane of the page. The electron velocity is perpendicular to the direction of the magnetic field lines.

[I mark]

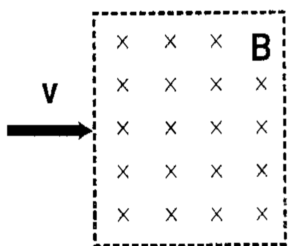
What is the direction of the magnetic force on the electron?

[2 marks]

(ii) Calculate the magnitude of the force.

[1 mark]

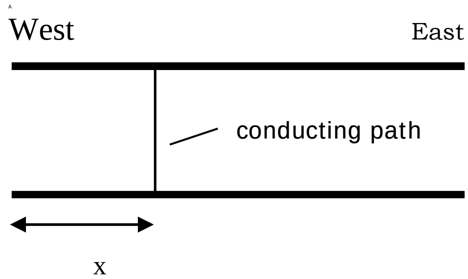
(iii) Describe the subsequent motion of the electron in the field.



Question B5. Resistors, Capacitors, and AC Circuits

[5 marks]

(a) A 10-km-long underground cable extends west to east and consists of two parallel wires, each of which has a resistance of 13 Ω/km. A short develops at distance x from the west end when a conducting path of resistance R connects the wires. The resistance of the wires and the short is then 100 Ω when the measurement is made from the west end, and 200 Ω, when it is made from the east end.



(i) Draw a labelled resistance diagram for the measurement taken from the west end. Draw a second diagram for the measurement taken from the east end.

(ii) Write down a pair of resistance equations which are consistent with your diagrams and the given facts, and hence determine x and R.

[2 marks]

(b) Five identical capacitors of capacitance C_o are connected in a bridge network. What is the equivalent capacitance between points *a* and *b?* Show your working.

a

[2 marks]

(c) Suppose we make a five-resistor bridge network by replacing each capacitor in (b) with a resistor of resistance R_o. What is the equivalent resistance between points *a* and *b?*

(d) In the circuit on the right, R = 50.0 Ω, C = 0.050 μF, and L = 200 mH. The oscillator voltage is 150 V_{rms}-

[1 mark]

(i) What is the resonant frequency ω_o in rad/s?

[3 marks]

(ii) At resonance, what rms voltage will be measured across each element?

[2 marks]

(iii) At resonance, what is V_{bd}, the voltage across the series combination of capacitor and inductor? Use a phasor diagram to help explain your answer.

[2 marks]

(i) Show that for the zeroth-order reflection, $\theta_{in}=\theta_{out}$.

The table below lists measurements taken of the interference pattern formed when light from a laser pointer (wavelength 633 nm) was shone onto a CD (compact disc).

The incoming angle was $\theta_{in} = 60°$.

θ_{out}	Order, m
18.5°	—1
61°	0
87°	+1
111.5°	+2
148°	+3

[7 marks]

(ii) Using these data and the reflective-grating equation, determine the grating spacing *d* for the CD. **Note**: For full marks, you should transform the data to give a straight-line graph which enables you to deduce *d* from the gradient of the line.

[2 marks]

(d) In what ways does the light produced by a domestic 60-W light-bulb differ from the light produced by a 60-W laser?

[5 marks]

(e) Using order-of-magnitude estimation with one-significant-figure arithmetic, come up with a realistic estimate for the amount by which a car tyre is worn down in one revolution during normal driving conditions. State all assumptions and approximations made, and clearly show your working and logic.

— End of Examination —