NZEST SCHOLARSHIP EXAMINATION 1994

PHYSICS

Time allowed: THREE hours

Ten minutes extra are allowed for reading this paper

INSTRUCTIONS TO CANDIDATES

1. The paper consists of 10 questions. The marks for each question are not equal and vary from 10 to 15. The total marks aggregate to 120.
2. You should attempt as many questions as you can in the available time. Although it is possible to answer all questions it is not expected that candidates will do so. Candidates are advised to invest their time in proportion to the marks indicated.
3. Correct numerical answers without adequate explanations will not necessarily receive full marks.

DATA WHICH MAY BE REQUIRED

Acceleration of gravity	g	=	$9.80\ \text{m s}^{-2}$
Permittivity of free space	ε_o	=	$8.85 \times 10^{-12}\ \text{F m}^{-1}$
Permeability of free space	μ_o	=	$4\pi \times 10^{-7}\ \text{H m}^{-1}$
Electronic charge	e	=	$1.60 \times 10^{-19}\ \text{C}$
Planck's constant	h	=	$6.63 \times 10^{-34}\ \text{J s}$
Speed of light	c	=	$3.00 \times 10^{8}\ \text{m s}^{-1}$
Speed of sound	v	=	$340\ \text{m s}^{-1}$

Question 1 *[12 marks]*

A group of Sports Science students at the University of Auckland investigate the simple aerodynamics of the flight of a tennis ball on a calm day using a tennis cannon fitted with a reliable timing device enabling the exit speed of the ball to be measured accurately for each firing to better than one-third of a percent (0.33%).

The experiment consists of repeated firings of the tennis ball vertically upwards under essentially the same conditions. Two students with stopwatches measure the time of ascent and descent of the ball for each firing. Simultaneously another two students, located on the third floor of the Science and Technology building immediately adjacent to the location of the launchings, observe through a window the altitude to which the ball rises. The latter two students find overall variations of approximately 40 cm in the altitude, enabling the group to establish the height above launch point to which the ball rises as 8.70 ± 0.20 metres. The data set obtained for the launch speed (v) and time of ascent ($\Delta t\uparrow$) and descent ($\Delta t\downarrow$) of the ball is as follows:

Shot number	v / m s^{-1}	$\Delta t\uparrow$ / sec	$\Delta t\downarrow$ / sec
1	14.1	1.19	1.40
2	14.2	1.24	1.41
3	14.3	1.25	1.47
4	14.1	1.19	1.47
5	14.1	1.22	1.50
6	14.1	1.30	1.37
7	14.1	1.28	1.44
8	14.2	1.22	1.42
9	14.1	1.16	1.49
10	14.2	1.30	1.44
11	14.2	1.18	1.44
12	14.3	1.19	1.41
13	14.0	1.25	1.33
Average Values	**14.2**	**1.23**	**1.43**

(a) What can you say about the significance of air resistance from these results? Justify your statement with an appropriate calculation.

[3 marks]

(b) Estimate the percentage, if any, of the initial kinetic energy that is lost doing work against air resistance during the ascent phase of the flight.

[3 marks]

(c) To what physical cause might you appropriately attribute the variation in height recorded by observers on the third floor given it was a windless day? Explain.

[3 marks]

(d) Explain, with a qualitative physical argument, how the effect of air resistance can account for the obvious difference in times recorded for ascent and descent.

[3 marks]

Question 2 ***[12 marks]***

(a) A bag of flour of mass m is suspended a height h above a platform of mass M that is supported above a rigid floor by a relatively light vertical spring system with an effective force constant k. The bag of flour is inadvertently released from its support and falls to the platform. Following impact, both the bag of flour and the platform descend on the spring system compressing it a (further) distance y. The system subsequently oscillates with simple harmonic motion (SHM).

There are four physical situations that need to be addressed to determine how far the spring system additionally compresses after the bag of flour collides with the platform. They are:

I Equilibrium of the platform before the collision

II The free fall of the bag of flour

III Impact of the bag of flour with the platform

IV Compression of the spring after impact.

(i) Write down the important physical quantity (or quantities) conserved in situation III and situation IV.

[2 marks]

(ii) Write down the appropriate physical equations for all four situations, defining any symbols you introduce.

[4 marks]

(iii) Now derive the quadratic equation in y in terms of the quantities m, M, h, k and the acceleration of gravity, g, that would enable you to determine y explicitly.

(**Note:** You are not required to solve this equation.) [2 marks]

(iv) Explain whether the frequency of the subsequent SHM oscillations of the bag of flour and platform are greater than, equal to, or less than those for the platform oscillating on the spring system alone.

[1 mark]

(b) At the entrance to a bay, the water is 1 metre above a horizontal reef at full tide. At low tide the reef projects 3 metres above the low water level. The motion of the tide can be taken as SHM and the time between successive low tides is 12 hours. For what time interval between low tides is the reef hidden from view?

[3 marks]

Question 3 *[15 marks]*

(a) Consider an object at rest that explodes into two fragments of masses m and M, with a release of energy Q that is all taken up in the kinetic energy of the two fragments.

(i) Show that the velocity V acquired by the fragment of mass M is given by:

$$V = \sqrt{\frac{2Qm}{M(m+M)}}$$

[4 marks]

(ii) Obtain an expression for the kinetic energy of the fragment of mass M in terms of Q.
[1 mark]

(iii) The nuclear reaction

$${}^{6}_{3}Li + {}^{1}_{0}n \rightarrow {}^{4}_{2}He + {}^{3}_{1}H$$

takes place for all energies of the incident neutrons. In an experiment in which a lithium target was bombarded with neutrons having energies of only a few electron volts, alpha particles with an energy of 2.04 MeV were detected.

Compute in MeV the energy Q released in the reaction. (The mass numbers of nuclei rather than their accurate values will suffice for this calculation).

[2 marks]

(b) Consider again the object and situation described in part (a) except that the explosion occurs when the object is moving with uniform velocity u relative to an observer at rest, with the mass M continuing in the same direction as its initial motion.

(i) Obtain an expression for the increase in the kinetic energy of the mass M due to the explosion. Compare the result obtained here with $\frac{1}{2}MV^2$, the increase obtained in part (a).

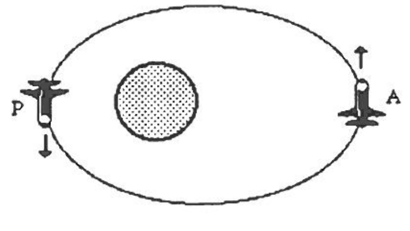
[**Note:** This event would appear exactly the same to an observer moving with the same uniform velocity u as it does to the observer at rest in part (a).]

[3 marks]

(ii) How do you reconcile the difference in these two answers recalling that the same stored energy Q has been released in both situations? [2 marks]

(iii) A manned spacecraft orbits a planet in an elliptical orbit as shown below. The astronaut on board wishes to escape from the planet and wishes to expend the minimum amount of fuel possible in the single rocket burn required. At which point of the orbit, A or P, should he make the burn? Explain. (No credit will be given to answers that simply state A or P).

For this situation you should assume that a rocket burn produces an instantaneous change in velocity, that the velocity change for a given mass of fuel consumed in the burn does not depend on the orbital position of the spacecraft, and that the rocket burn is made tangential to the spacecraft's orbital path.



[3 marks]

Question 4 *[10 marks]*

The trapeze is one of the most exciting performing acts of a circus. 'Flyers' fly through the air performing daring somersaults before being caught by the 'catcher' member of their act.

Arthur Concello and his wife Antoinette won fame on the flying trapeze, Antoinette becoming the first woman to perform a triple somersault in which she rotated her body through three complete rotations in mid air before being caught by Arthur.

(a) A slow motion analysis of the flight of a successfully completed 'triple' indicates that it lasts a period of 1.90 secs and that the first and last quarter revolutions are made with the flyer's body in an extended orientation. During the intermediate stage of the flight a moderate tuck orientation is adopted. Further analysis of the flight indicates a time of 0.40 secs elapses during the first quarter revolution completed, whilst the flyer's rotational inertia about her centre of mass in the extended orientation is known to be 19.0 kg m^2.

(i) What important principle of Physics is exploited by the flyer in performing such death defying feats?

[1 mark]

(ii) Determine the flyer's angular velocity during the first quarter revolution of the triple somersault described.

[2 marks]

(iii) Estimate the rotational inertia of the flyer's body about her centre of mass during the intermediate tuck orientation of the feat.

[3 marks]

(b) In 1982 the first quadruple somersault was achieved before an audience by Miguel Vasquez when he rotated his body through four complete circles into the arms of his brother Juan, the catching member of their act. If Miguel's rotational inertia in the extended orientation about his centre of mass was 20.0 kg m^2 and he completed the feat under the same flight conditions as the 'triple' described above (1.90 secs through the air with the first and last quarter revolutions made in the extended orientation and each taking 0.40 secs of time to complete), what rotational inertia must he have reduced his body to during the tight tuck for the intermediate phase of his flight?

[2 marks]

(c) Consider another talented trapeze artist taller than Miguel who wishes to execute a quadruple but who cannot get his body into a tight enough tuck to complete the feat under the conditions used by Miguel. In what way would he have to modify the conditions to achieve the feat? Would you expect this modification to make it easier or harder for his partner to make the catch? Explain.

[2 marks]

Note: Throughout the course of your calculations you may ignore the effects of air resistance.

Question 5 *[12 marks]*

The speed of ocean waves v depends on their wavelength λ and also on the depth h of the water. For the two extreme cases of deep water (when $h \gg \lambda$) and shallow water (when $h \ll \lambda$) the physical expressions for the wave speed take the simple forms:

$$v = \sqrt{g\lambda/2\pi} \quad - \quad \text{deep water waves}$$

$$v = \sqrt{gh} \quad - \quad \text{shallow water waves}$$

Normally ocean waves are generated by the wind and have wavelengths ranging from metres up to hundreds of metres. However, earthquakes on the ocean floor can give rise to waves of extremely long wavelength the order of hundreds of kilometres. The sudden motion of the ocean floor disturbs the water and generates waves on the surface. These waves are called tsunamis or tidal waves and have wavelengths that are typically 100 - 400 km. In the open sea tsunamis have amplitudes of a metre or less but when such waves reach the relatively shallow water of the continental shelf their heights can reach tens of metres resulting in great devastation in harbour areas. The power carried by a tsunami, like any travelling wave, can be assumed proportional to vf^2A^2 where f is the frequency and A the amplitude of the wave. Furthermore for distances less than 2000 km, the surface of the earth may be regarded as flat and the intensity of the wave decreases as the inverse of its distance from its source.

Consider a tsunami originating in the Pacific Ocean where the average depth is 4.3 km. It passes under two ships, one a frigate located 500 km from the source, the other a tanker 1500 km from the source. A recording station in Hawaii which monitors the height of water as a function of time records a cycle of high then low then high water levels over a 10 minute period.

(a) How much time elapses between the tsunami first reaching the frigate and the tanker? [1 mark]

(b) Estimate the wavelength of the tsunami in the open sea. [2 marks]

(c) If the tsunami has an amplitude of 100 cm when it passes the tanker, what was its amplitude when it reached the frigate? [1 mark]

(d) Determine the maximum vertical velocity and acceleration that the tsunami gives to the tanker. Will the crew of the tanker notice the passing of the tsunami? Explain. [3 marks]

(e) Assuming that the power in the tsunami remains constant when it enters the coastal shallows, show that its amplitude varies as;

$$h^{-1/4}$$

[2 marks]

(f) Suppose the tanker is just outside the continental shelf when struck by the tsunami. Estimate the amplitude of the tsunami in a coastal region near the tanker where $h = 10$ metres. [2 marks]

(g) What is the wavelength of the tsunami in this coastal region? [1 mark]

Question 6 *[10 marks]*

(a) Men who enjoy singing in the shower are often described as bathroom baritones. A major reason why bathroom baritones flourish is that their voice resonates in the cavity formed by the shower cubicle. Consider a shower cubicle that measures 1.2 m x 1.2 m x 2.7 m. Determine the four lowest resonant frequencies a bathroom baritone excites in such a cubicle.

[**Note:** Consider only those resonances excited between parallel surfaces in answering this question.]

[3 marks]

(b) A radio wave undergoes a phase shift of 180° when it reflects from the calm surface of the ocean. In the early days of radioastronomy, Australian astronomers observed the interference between a radio wave arriving at their antenna on a direct path from the Sun and on a path involving one reflection from the sea surface. If their antenna was located on the coastline 25 metres above sea level and the radio waves had a frequency of 60 MHz, find the least angle above the horizon for the Sun that results in destructive interference of the waves at the receiving antenna.

[**Note:** The trigonometric identity $\cos 2\theta = 1 - 2\sin^2\theta$ may be useful.]

[4 marks]

(c) Interference effects can sometimes be detected by sound waves passing through picket fences. John and Michael are brothers that live on a property possessing a long picket fence. The picket fence has vertical air gaps spaced 16 cm apart. They agree to investigate the effects produced by their fence. John positions himself a relatively large distance away from the fence such that the line joining himself to the centre of the fence makes an angle of 30° to the normal to the fence. Michael positions himself on the other side of the fence a similar distance from it but square-on to the centre of the fence. Michael has an audio-oscillator/loud-speaker system and sweeps it through the frequency range 20 Hz – 15 kHz. Which frequencies will John hear at an enhanced level due to the intervening presence of the picket fence?

[3 marks]

Question 7 *[15 marks]*

A microscopic sphere of tungsten, carrying the charge equivalent of several electrons, can be levitated and observed in the uniform electric field of a parallel plate capacitor when sufficient care is taken. Furthermore, the charge on this microsphere may be either increased or decreased in integral amounts of the electronic charge, *e*, with the skilled use of a radioactive source. When such a charge change occurs, an adjustment of the potential difference between the capacitor plates will ensure that the microsphere remains in equilibrium.

(a) In an experiment to determine the charge q on a tungsten microsphere a physicist first balances the particle for a potential difference V, then changes the charge on it by an unknown but integral multiple Δn of the electronic charge and rebalances it with a new value of potential difference V'. Find an expression that relates the charge q to the charge change $e\,\Delta n$ and the potential difference values V and V'.

[4 marks]

(b) In a series of charge changes with a particular tungsten microsphere the following values of potential difference, each with an uncertainty of $\pm$ 20 volts, are required for equilibrium:

16,350 volts, 11,670 volts, 16,330 volts, 13,610 volts

A different, additional measurement establishes that the magnitude of the charge on the microsphere at these particular equilibrium voltages *must be* $< 10e$.

(i) Determine the number of excess electronic charges on the microsphere at each of the above four equilibrium voltages. [6 marks]

(ii) If the plate separation of the capacitor is 30 mm, calculate the radius of the tiny microsphere. (The density of tungsten is 19,300 kg m^{-3}, the acceleration due to gravity 9.80 m s^{-2}, and the electronic charge 1.60×10^{-19} C)

[5 marks]

Question 8 ***[12 marks]***

You are required to build a cylindrical solenoid that will maximise the magnetic field possible within the constraints of the materials and equipment you are provided with. You have a power supply capable of supplying 15 W of power, but which is current limited to 0.30 ampere. The former on which the solenoid is to be wound is 2.0 cm in radius and 50 cm long. You have 1.0 kg of copper at your disposal but a neighbour has a wire-extruding machine that permits you to make any size cylindrical wire you desire. Furthermore, the wire can be coated with an insulating material of negligible thickness.

(a) Explain how to build a solenoid that maximises the magnetic field. [4 marks]

(b) Determine the maximum magnetic field possible indicating full details of the solenoid winding. [8 marks]

Note: (i) Your textbook on magnetism lists the magnetic field strength B of such a cylindrical solenoid carrying current I as:

$$B = \mu_o \, n \, I$$

(ii) You may disregard the marginal effect the increasing radius of successive layers of turns has in arriving at your answer for B.

(iii) Copper has a density of 8,890 kg m^{-3} and a resistivity of 1.72 x 10^{-8} Ω m

Question 9 *[12 marks]*

Martin is a physics teacher in a girls' school that has a well-equipped physics laboratory with quality AC/DC voltmeters and ammeters, stabilized 12 volt/50 Hz AC supplies and general circuit componentry with accurately known values of their electrical properties. He sets out to test the ingenuity of his best two pupils, Anna and Catherine, by requiring them to determine the inductance *L* of a coil of wire that he has wound around an iron core. To demonstrate the non-ideal nature of the coil he connects it in series with a DC ammeter to a battery and the ammeter shows a reading of a few amperes. He then tells them to go off and in turn measure its inductance *L*, as best they can, using whatever equipment is available in the laboratory.

Anna is first to try. She selects a variable capacitor, that Martin sometimes uses in electrical resonance demonstrations, whose capacitance can be accurately varied over the range 100 - 300 μF. She connects this variable capacitor in series with the coil to a 12 volt/50 Hz AC supply. She monitors the voltage across both the coil and the capacitor, carefully adjusting the latter until the two voltages are exactly equal. The value of the capacitance at which this occurs is 219 μF. From this she uses her knowledge of the resonant frequency condition in a simple AC series circuit, namely,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

to obtain a value of 46.3 mH for the inductance.

Catherine then has her turn. She selects a 6.00 Ω resistor from the store and connects it in series with the coil and an AC ammeter to a 12.0 volt/50 Hz AC supply. A current of 0.657 ampere is recorded on the ammeter. She additionally measures the voltage across both the resistor and the coil, obtaining values of 3.94 volts (resistor) and 9.53 volts (coil), respectively. These data, used intelligently, enable her to obtain the correct value of the inductance.

Both students notice that the coil becomes quite warm after the current had been maintained in it for some time. They subsequently question Martin about the temperature coefficient of the resistivity of the wire but are assured that it is very low and not the cause of the variability in their results.

(a) Determine the correct value for the inductance using Catherine's measurements. [5 marks]

(b) What is it about Anna's method for determining the inductance that makes it inferior? Give a full explanation backed by adequate calculation and reasoning to justify your answer. [4 marks]

(c) Explain why the sum of the voltages Catherine measures across the resistor and the coil is greater than the voltage of the AC supply. [1 mark]

(d) Describe two factors that directly contribute to the warming of the coil. [2 marks]

Question 10 ***[10 marks]***

(a) Physics teachers are now able to demonstrate Young's double slit experiment readily in a classroom using laser light.

(i) What are two of the special properties of laser light that make it suitable for demonstrating Young's experiment?

[2 marks]

(ii) What property of light does Young's experiment demonstrate?

[1 mark]

(b) A laser with a light power output of 1 mW emits monochromatic radiation of wavelength 530 nm. It is used by a physics teacher to demonstrate the phenomena of diffraction and the photoelectric effect.

(i) What is the energy difference in units of eV between the two atomic energy states that gives rise to laser radiation of this wavelength?

[2 marks]

(ii) A transmission grating of 500 lines/mm is used to diffract the laser light onto a screen located 2.00 m from the grating. Determine the separation on the screen between the two first order maxima.

[2 marks]

(iii) The laser is then shone directly onto the cesium photocathode of a photoelectric cell. The photocathode has a work function of 1.90 eV and a conversion efficiency of 10^{-5} (i.e. one photoelectron produced for every 10^5 photons incident). Explain whether a photoelectric current can be made to flow across the cell. Calculate the magnitude of any such current.

[3 marks]

End of Paper