Canadian Association of Physicists
1999 Prize Exam

This is a three hour exam. National ranking and prizes will be based on a student's performance on both sections A and B of the exam. However, performance on the multiple choice questions in part A will be used to determine whose written work in part B will be marked for prize consideration by the National Committee. The questions in part B of the exam have a range of difficulty. Please be careful to gather as many of the easier marks as possible before venturing into more difficult territory. In some cases an answer to part (a) of a question is needed for part (b). Should you not be able to solve part (a), assume a likely solution and attempt the rest of the question anyway. No student is expected to completely finish this exam and parts of each question are very challenging.

Non-programmable calculators may be used. Please be very careful to answer the multiple choice questions on the answer card/sheet provided to you and, most importantly, write your solutions to the three written problems on separate sheets as they will be marked by different people in different parts of Canada. Good luck.

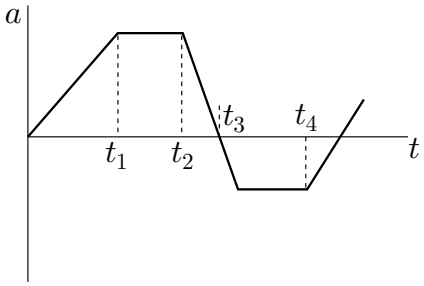
Data

Speed of light	$c = 3.00 \times 10^8$ m/s
Gravitational constant	$G = 6.67 \times 10^{-11}$ Nm^2/kg^2
Radius of Earth	$R_E = 6.38 \times 10^6$ m
Radius of Moon	$R_M = 1.70 \times 10^6$ m
Mass of Earth	$M_E = 5.98 \times 10^{24}$ kg
Mass of Moon	$M_M = 7.35 \times 10^{22}$ kg
Mass of Sun	$M_S = 1.99 \times 10^{30}$ kg
Radius of Moon's orbit	$R_{EM} = 3.84 \times 10^8$ m
Radius of Earth's orbit	$R_{ES} = 1.50 \times 10^{11}$ m
Acceleration due to gravity	$g = 9.81$ m/s^2
Fundamental charge	$e = 1.60 \times 10^{-19}$ C
Mass of electron	$m_e = 9.11 \times 10^{-31}$ kg
Mass of proton	$m_p = 1.673 \times 10^{-27}$ kg
Mass of neutron	$m_n = 1.675 \times 10^{-27}$ kg
Planck's constant	$h = 6.63 \times 10^{-34}$ Js
Coulomb's constant	$1/4\pi\epsilon_o = 8.99 \times 10^9$ Nm^2/C^2
Permeability of free space	$\mu_o = 4\pi \times 10^{-7}$ N/A^2
Speed of sound in air	$v_s = 340$ m/s
Density of air	$\rho = 1.2$ kg/m^3
Boltzmann constant	$k = 1.38 \times 10^{-23}$ J/K
Absolute zero	$T = 0$ K, $T = -273^\circ$C
Energy Conversion	1 cal=4.184 J
Avogadro's number	$N_A = 6.02 \times 10^{23}$ mol^{-1}

Part A: Multiple Choice

Question 1

The time dependence of the acceleration of a car is as shown. Which time corresponds to the maximum speed of the car?



(a) t_1
(b) t_2
(c) t_3
(d) t_4

Question 2

Two identical loudspeakers are supplied with identical sinusoidal signals. They are placed close to one another in a room and it is noted that there are regions of increased and decreased sound intensity in the vicinity of the speakers. Which of the following actions will not change this pattern?

(a) Moving one of the speakers.
(b) Changing the amplitude of the signal.
(c) Changing the frequency of the signal.
(d) Replacing the air in the room with Helium gas.

Question 3

Two black objects of the same diameter, a sphere and a disc, are placed in front of a uniform beam of light. The plane of the disc is perpendicular to the light rays. The force acting upon them by the light is:

(a) zero
(b) bigger on the disc.
(c) bigger on the sphere.
(d) the same on both.

Question 4

A 1 kg mass rests on the ground, at sea-level and at the equator. What would its weight be if the earth were spinning ten times faster than is presently the case?

(a) 9.80 N
(b) 3.37 N
(c) 6.43 N
(d) 9.76 N

Question 5

An ideal Ammeter—a device to measure current in an electrical circuit—should have an internal resistance which is,

(a) zero.

(b) infinite.

(c) equal to the resistance of the circuit's load.

(d) equal to the internal resistance of the circuit's power source.

Question 6

A 100,000 kg aircraft drops a 1000 kg package of supplies over an arctic research station. What approximate force is felt by the 100 kg pilot at the instant of the release?

(a) 1 N

(b) 10 N

(c) 100 N

(d) zero

Question 7

A converging lens forms an image of an object on a screen. The image is real and has twice the size of the object. If the positions of the screen and the object are interchanged, leaving the lens in its original position, what is the new image size on the screen?

(a) Twice the object size.

(b) Same as the object size.

(c) Half the object size.

(d) Can't say as it depends on the focal length of the lens.

Question 8

A bucket full of water is attached to the end of a rope and allowed to swing back and forth as a pendulum from a fixed support. The bucket has a hole in its bottom that allows water to leak out. How does the period of motion change with the loss of water?

(a) The period does not change.

(b) The period continuously decreases.

(c) The period continuously increases.

(d) The period increases to some maximum and then decreases again.

Question 9

A pencil is placed vertically on a table top with its pointy end up and its sticky eraser end down. As it falls over from this unstable position, its point of contact with the table remains stationary. During its fall, the acceleration of its tip,

(a) remains less than g at all times.

(b) exceeds g at some point.

(c) becomes g just before hitting the table.

(d) is constant.

Question 10

Two 20 g worms climb over a 10 cm high, very thin, wall. One worm is thin and 20 cm long. The other is fat (but still thin compared to its length) and only 10 cm long. What is the ratio of the potential energy of the thin worm as compared to that of the fat worm when each is half way over the top of the wall?

(a) 1:1

(b) 2:1

(c) 2:3

(d) 1:2

Question 11

Suppose that the "Man Who Skied Down Everest" went straight down an incline of 40° to the horizontal and subject to a coefficient of kinetic friction of 0.10. Starting from rest, how long did it take him to reach a speed of 50 km/hr (Ignore air resistance)?

(a) 2.5 s

(b) 9.0 s

(c) 1.5×10^2 s

(d) 2.0 s

Question 12

A stone is thrown vertically downward from the edge of a cliff with an initial speed of 10 m/s. Just before hitting the ground, it has a final speed of 30 m/s. If instead, the stone were thrown horizontally outwards from the top of the cliff with the same initial speed as before, what final speed would it have immediately before hitting the ground?

(a) 10 m/s

(b) 20 m/s

(c) 30 m/s

(d) 40 m/s

Question 13

Two objects of equal mass, and heading towards each other with equal speeds, undergo a head-on collision.Which of the following statements is correct?

(a) Their final velocities must be zero.

(b) Their final velocities may be zero.

(c) Each must have a final velocity equal to the other's initial velocity.

(d) Their velocities must be reduced in magnitude.

Question 14

A positive point charge $+Q$ is placed at $x = 0$ and a negative point charge $-Q$ is placed at $x = a$. The magnitude of the electrostatic force between the two is F. If another point charge $+Q$ is paced at $x = -a$, the net force on the charge at the origin ($x = 0$) is,

(a) $2F$ in the negative x-direction.

(b) F in the positive x-direction.

(c) $5F/4$ in the positive x-direction.

(d) $2F$ in the positive x-direction.

Question 15

A simple circuit contains an ideal battery and a resistance R. If a second resistor is placed in parallel with the first,

(a) the potential across R will decrease.

(b) the current through R will decrease.

(c) the current delivered by the battery will increase.

(d) the power dissipated by R will increase.

Question 16

A positively charged insulator is brought near (but does not touch) two metallic spheres that are in contact. The metallic spheres are then separated. The sphere which was initially farthest from the insulator will have,

(a) no net charge.

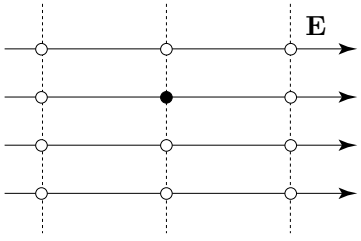
(b) a negative charge.

(c) a positive charge.

(d) either a positive or negative charge.

Question 17

A uniform electric field is as shown. How many of the labelled points have the same electric potential as the shaded point?



(a) 2

(b) 3

(c) 4

(d) 8

Question 18

A spherical capacitor is formed by two metallic and concentric spherical shells. The capacitor is then charged so that the outer shell carries a positive charge and the inner shell carries an equal but negative charge. Even if the capacitor is not connected to any circuit, the charge will eventually leak away due to the small conductivity of the material between the shells. What is the character of the magnetic field induced by this leakage current?

(a) Radially outwards from the inner shell to the outer shell.

(b) Radially inwards from the outer shell to the inner shell.

(c) Circular field lines between the shells and perpendicular to the radial direction.

(d) No magnetic field is induced.

Question 19

Which of the following has units of magnetic field?

(a) kg C^{-1} s^{-1}

(b) kg A^{-1} s^{-1}

(c) N C^{-1} m^{-1}

(d) J A^{-1} m^{-1}

Question 20

Near the geographic north pole is the magnetic north pole which is, in fact, a south magnetic pole. At this point, the earth's magnetic field points straight down. An electron is projected southwards and horizontally from the magnetic north pole. The magnetic force on the electron will cause it to be deflected to the,

(a) Up

(b) Down

(c) East

(d) West

Question 21

A diffraction grating has 300 "lines" per mm etched upon it. When light of wavelength 550 nm is normally incident upon the grating, how many bright spots appear on a screen a short distance away?

(a) 1

(b) 6

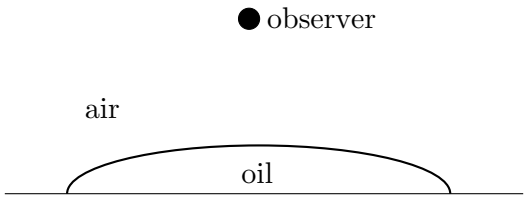
(c) 12

(d) 13

Question 22

A drop of oil ($n = 1.4$) is on a glass ($n = 1.5$) sheet and is observed from directly above by reflected white light.

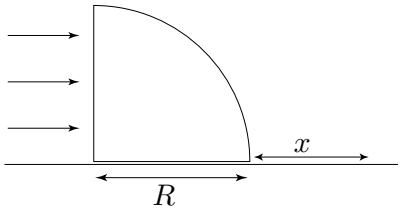
A number of circular constructive interference bands are observed for each colour in the visible spectrum. Approximately how thick is the oil film where one observes the third blue band from the outside edge of the drop. The wavelength of blue light may be taken to be $\lambda_b = 450$ nm.



(a) 482 nm
(b) 675 nm
(c) 1125 nm
(d) 1350 nm

Question 23

A uniform, horizontal beam of light is incident upon a prism as shown. The prism is in the shape of a quarter-cylinder, of radius $R = 5$ cm, and has the index of refraction $n = 1.5$. A patch on the table top for a distance x from the cylinder is unilluminated. The value of x is,



(a) 1.71 cm
(b) 2.24 cm
(c) 2.50 cm
(d) 5.00 cm

Question 24

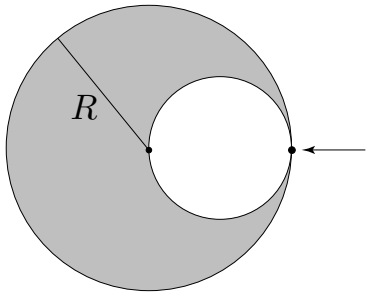
Consider the following types of electromagnetic radiation: radio waves, infra-red, visible light. Which of the following statements are true?

(i) only radio waves can be used to transmit audio information.
(ii) only infra-red radiation is emitted by very hot objects.
(iii) only visible light can be detected by humans.

(a) only i is true.
(b) only ii is true.
(c) only iii is true.
(d) None of the statements are true.

Question 25

In the film Armageddon, astronauts land on an asteroid and are able to walk around "normally" due to the gravitation of the large rock. Suppose that a spherical asteroid has a mass M and a radius R. A spherical hole of radius $R/2$ is excavated from the asteriod as shown. What is the gravitational acceleration at a point on the surface of the asteroid at a point just above the excavation?

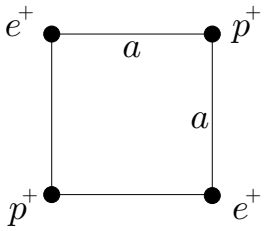


(a) $\frac{GM}{R^2}$
(b) $\frac{GM}{2R^2}$
(c) $\frac{GM}{8R^2}$
(d) $\frac{7GM}{8R^2}$

Part B

Question 1

Four charges, each of charge $+e$, are at the four corners of a square of side $a = 1$ cm. The four charges are fixed in place and are considered to be of point-size. Gravity plays no role in this question.



(a) Sketch a diagram of the electric field due to this charge system.

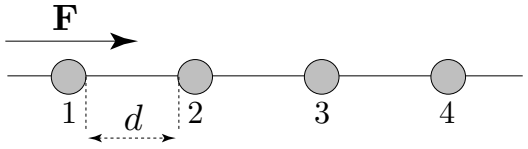
(b) What is the net force acting upon one of the charges?

(c) What is the electrostatic potential energy of this charge system?

(d) Now suppose that two of the charges are protons and the other two are positrons. A positron is the electron's anti-particle. It has the same mass as an electron but a charge of $+e$. The four charges are suddenly released. What are their speeds when they are a significant distance apart from one another?

Question 2

Suppose that we have a string of equally spaced beads of mass m, their surfaces being separated by a distance d, that are free to slide without friction on a thin wire. Suppose that a constant force F acts on the first bead, initially at rest, causing it to accelerate along the wire as shown. This force acts only on the first bead and might be created by a well directed, steady stream of air. The first bead will collide with the second, which will in turn collide with the third, and so on. Suppose that all collisions are elastic.



(a) What is the speed of the first bead immediately before and immediately after its collision with the second bead?

(b) What is the speed of the second bead immediately before and immediately after its collision with the third bead?

(c) Remember that the constant force is always acting upon the first bead. What is the time interval between subsequent collisions between the first and second beads? What then is the average speed of the first bead? What is the speed of the "shock wave" that travels down the wire?

(d) If the whole process is repeated, but with collisions which are perfectly inelastic, what is the terminal speed of the shock wave formed?

Question 3

From everyday experience and observations, estimate the brightness of a full moon as compared to the noon day sun. Brightness is defined as the luminous intensity as measured in units of power per unit area. To arrive at a reasonable numerical estimate, you will need to estimate some physical parameters. It is essential that you explain the reasoning behind your estimates and include detailed drawings and explanations to support your arguments.