Canadian Association of Physicists
1994 Prize Exam

This is a three hour exam. National ranking and prizes will be largely based on a student's performance on the three questions in part B of the exam for which written solutions are required. However, performance on the multiple choice questions in part A will be used to determine whose written work will be marked for prize consideration.

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, say, 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 finish this exam and part (d) of each question is very challenging and will likely be solved correctly by only a few of the very top Canadian physics students.

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 locations. Good luck.

Data

Speed of light	$c = 3.00 \times 10^8$ m/s
Gravitational constant	$G = 6.67 \times 10^{-11}$ Nm²/kg²
Radius of Earth	$R_E = 6380$ km
Mass of Earth	$M_E = 5.98 \times 10^{24}$ kg
Mass of Sun	$M_S = 1.99 \times 10^{30}$ kg
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	$e = 1.6 \times 10^{-19}$ C
Mass of electron	$m_e = 9.1 \times 10^{-31}$ kg
Mass of proton	$m_p = 1.67 \times 10^{-27}$ 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
Magnetic constant	$\mu_o = 4\pi \times 10^{-7}$ N/A^2
Speed of sound in air	340 m/s

Part A: Multiple Choice

Question 1

It was once proposed to use a 2 km vertical Sudbury mine shaft for microgravity experiments in a vacuum. How much time would scientists have to do an experiment during one drop?

(a) 20 s
(b) 63 s
(c) 0.64 s
(d) 198 s

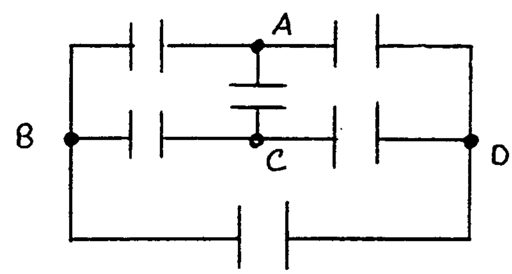
Question 2

If the moon were twice as massive as it is now, and it stayed at the same orbital radius about the earth as it has now, its new orbital period (in terms of its current orbital period T) would be,

(a) T
(b) $T/2$
(c) $T/4$
(d) $2T$

Question 3

In the following circuit composed of identical capacitors, across which terminals would you connect a battery in order for all the capacitors to charge up.



(a) AB
(b) AC
(c) BD
(d) None of the above.

Question 4

Two cylindrical resistors, one of length l and radius r, and the other of length $3l$ and radius $3r$, are made of the same materials. If the resistance of the smaller one is R, what is the resistance of the larger one?

(a) $R/3$
(b) $3R$
(c) $9R$
(d) $27R$

Question 5

A simple pendulum consists of a mass m attached to a light string of length l. If the system is oscillating through small angles, which of the following is true?

(a) The frequency is independent of the acceleration due to gravity, g.
(b) The period depends on the amplitude of the oscillation.
(c) The period is independent of the mass m.
(d) The period is independent of the length l.

Question 6

An astronaut in the space shuttle orbiting the earth performs a trick for a television audience. She inflates a helium filled balloon within the shuttle's controlled atmosphere and lets go of it. To the astonishment of all watching, the balloon
(a) hovers in place where it was released.
(b) rises noticeably away from the earth.
(c) falls noticeably towards the earth.
(d) drifts backwards opposite to the direction of the shuttle's velocity.

Question 7

A boat has a green light (with wavelength $\lambda = 500$ nm) on its mast. What wavelength would be measured and what colour would be observed for this light as seen by a diver submerged in water (index of refraction $n = 1.33$) by the side of the boat.
(a) Green $\lambda = 500$ nm
(b) Red $\lambda = 665$ nm
(c) green $\lambda = 376$ nm
(d) UV $\lambda = 376$ nm

Question 8

A radio station transmits using a vertical mast. The antenna in your radio is a coil (solenoid) wrapped around a ferrite (iron) rod. What orientation must this antenna have for optimum reception?
(a) Rod pointing at mast.
(b) Rod parallel to mast.
(c) Horizontal rod pointing 90° from the line of the mast.
(d) Horizontally oriented rod directly above the mast.

Question 9

You have ten identical filters. One is placed in front of a white light and the light appears red. When all ten are placed in front of the light, it appears to be a dim green colour. Which of the following is a possible transmission characteristic for one of the filters?

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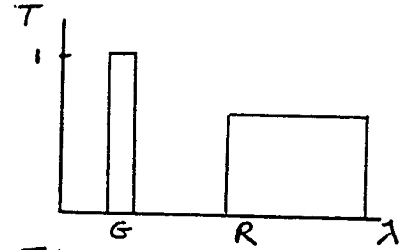

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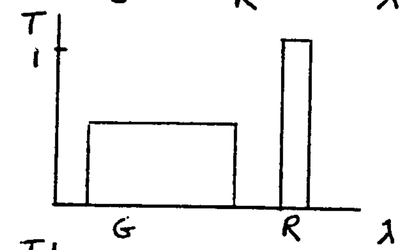

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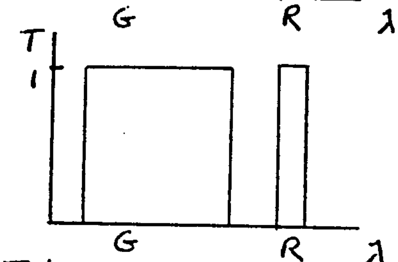
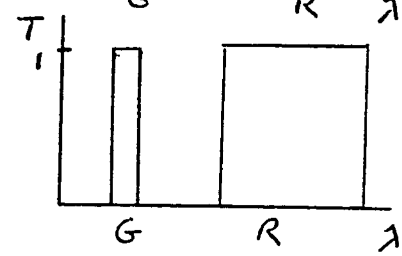
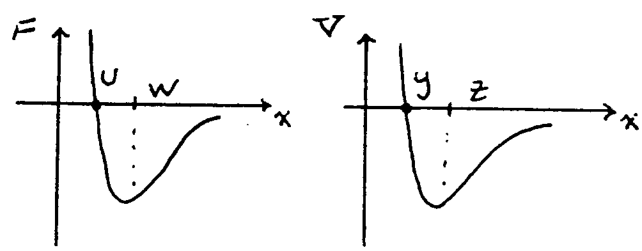


(d)


Question 10

Two atoms interact with each other according to the following force F, and potential, V diagrams. What is their equilibrium separation?



(a) The separation u which is equal to y
(b) The separation u which is equal to z
(c) The separation w which is equal to y
(d) The separation w which is equal to z

Question 11

A ball is thrown into the air with an initial speed u. The time interval taken for the ball to rise to its maximum height is t_r. The time interval taken for it to fall back down from this maximum height to its original position is t_f. Under "real life" conditions, which of the following is satisfied by t_r and t_f.

(a) $t_r > t_f$
(b) $t_r < t_f$
(c) $t_r = t_f$
(d) $t_r > t_f$ if u is great enough.

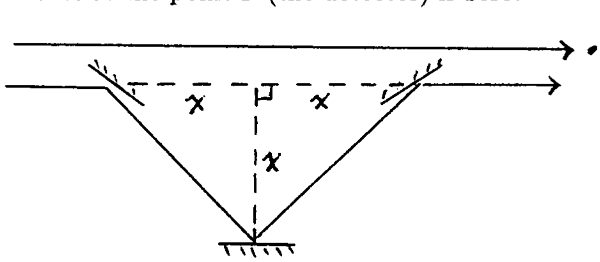
Question 12

An airplane flies a straight path from town A to town B, 500 km away. Town B is due east of town A and a strong wind blows from north to south at 300 km/hr. If the plane's airspeed is 900 km/hr, which of the following statements is true?

(a) Trip time is $\frac{5}{3\sqrt{8}}$ hr.
(b) Plane's ground speed is 600 km/hr.
(c) Plane's heading is 30° North of East.
(d) None of the above.

Question 13

Microwaves of wavelength $\lambda = 5.0$ cm, and intensity I_o, are split and recombined by the metallic mirror system shown. What should x be so that the intensity of the microwaves at the point P (the detector) is zero.



(a) 0.88 cm
(b) 3.54 cm
(c) 6.04 cm
(d) 3.02 cm

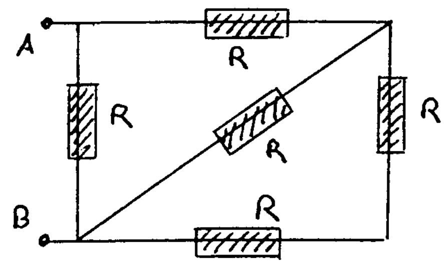
Question 14

Which of the following is a possible expression for the Rydberg, a unit of energy?

(a) $e^4/8m_e\epsilon_o h^2$
(b) $\epsilon_o^2 h^2/8m_e e^4$
(c) $m_e e^4/8\epsilon_o^2 h^2$
(d) $m_e c^2/\epsilon_o he$

Question 15

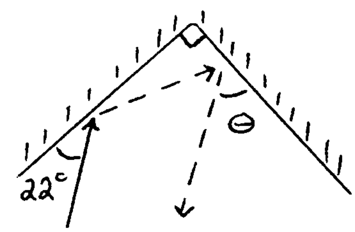
Consider the network of identical resistors shown. The equivalent resistance between the points A and B is,



(a) $5R$
(b) $R/2$
(c) $5R/8$
(d) $2R$

Question 16

A ray of light is directed towards a corner reflector as shown. The incident ray makes an angle of 22° with one of the mirrors. At what angle θ does the ray emerge?



(a) 22°
(b) 68°
(c) 44°
(d) None of the above.

Question 17

Many people's glasses appear to be a blue-green colour when viewed under reflected light. A thin film of index of refraction $n = 1.35$ is applied to the outside surface of the glass so that the film/glass interface does not reflect any red light of wavelength $\lambda = 630$ nm. What thickness must the film layer be in order to achieve this? Take the index of refractions of air and glass to be 1.0 and 1.6 respectively.

(a) 157.5 nm
(b) 315.0 nm
(c) 233.3 nm
(d) 116.7 nm

Question 18

A mass M has the same kinetic energy as a mass m. The ratio of their momenta, p_M/p_m, is,

(a) $\sqrt{M/m}$
(b) $\sqrt{m/M}$
(c) $(m+M)/M$
(d) $(m+M)^2/mM$

Question 19

A stream of water droplets, each of mass $m = 0.001$ kg, are fired horizontally at a velocity of 10 m/s towards a steel plate where they collide. The droplets are spaced equidistantly with a spacing of 1 cm. What is the approximate average force exerted on the plate by the water droplets assuming that they do not rebound after their collision.

(a) 10 N
(b) 100 N
(c) 1 N
(d) 0.1 N

Question 20

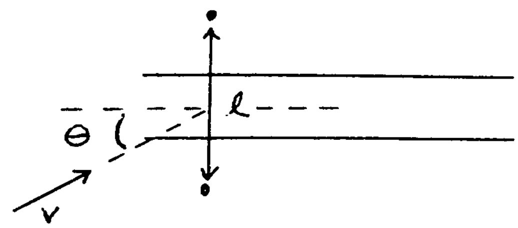
Three identical balls are thrown from the top of a cliff and some time later land at the base of the cliff. Ball A is thrown upwards with speed v, Ball B is thrown downwards with speed v, and Ball C is thrown at speed v and at an angle of 45° above the horizontal. Comparing the speeds, v_A, v_B, and v_C with which the balls hit the ground at the base of the cliff (and ignoring air resistance), you find,

(a) $v_A = v_B > v_C$
(b) $v_A > v_C > v_B$
(c) $v_A = v_B = v_C$
(d) $v_B > v_C > v_A$

Part B

Question 1

In this question we will investigate a possible navigational aid for aircraft approaching an airport. Suppose at one end of a runway there are two radio transmitting towers, one on either side of the runway, separated by a distance $l = 100$ m. The two radio towers are each transmitting a radio signal of frequency $f_o = 12$ MHz in phase with each other. An aircraft with a ground speed of v is flying towards the airport such that its velocity makes an angle θ with the runway as shown. The aircraft, still very far from the airport, has locked onto the signals and is heading directly for the midpoint of the towers.



(a) At the aircraft's current position, the intensity of the signal from each tower separately would be I_o. Find the intensity of the combined signal from both towers received by the aircraft for headings of $\theta = 0$ and $\theta = \pi/2$.

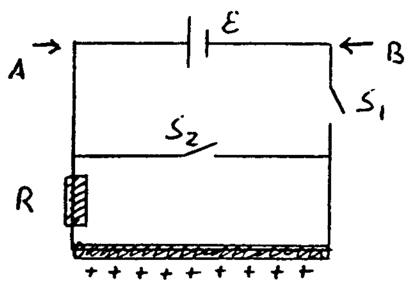
(b) For what headings would the aircraft receive no signal? If the aircraft was commanded to approach the airport with a heading of 30°, what kind of a signal should the captain expect from the radio towers?

(c) The aircraft gets slightly off course and is approaching the airport on a heading of $\theta = 0$ but is heading directly for one of the transmitting towers (as opposed to their midpoint). The aircraft is still very far from the airport but as it draws nearer, the intensity of the signal received from the radio towers starts to drop. How far is the aircraft from the nearest tower when the signal has dropped to a minimum?

(d) The aircraft, back on course now, is approaching the airport with a ground speed of 500 km/hr and on a heading with $\theta = 30°$. The aircraft has a circuit which generates its own 12 Mhz reference signal and compares it to the one being received from the radio towers. A beat is detected in the sum of the two signals. What is the beat frequency? The navigator quickly programs the on-board computer to calculate the aircraft's ground speed in terms of this beat frequency Δf. When the beat frequency is 10 Hz and the signal received from the towers is lower than the 12 Mhz on-board reference signal, what is the plane's ground speed?

Question 2

Consider the circuit shown with the two switches S_1 and S_2. The battery has an emf of $\epsilon = 6$ V and the resistor has a resistance of $R = 1.0\ \Omega$. The bottom wire is encased in an insulated wrapping of mass $M = 0.1$ kg which carries a positive static charge of $Q = 10$ mC. Assume that the masses of all other wires and components are very small as compared to this charge bearing wrapping. The dimensions of the circuit are $l = 5$ cm square. The bridge (or middle connecting) wire, with S_2 in it, is $l/2$ above the bottom wire. The contraption is suspended in such a way that it may pivot about the top wire on the axis AB; the circuit maintains its shape regardless of the switch configuration. A magnetic field, $B = 10.0$ T, and an electric field, $E = 1000$ N/C, both point out of the page.



(a) With both switches open, find the equilibrium angle θ that the plane of the circuit makes with the vertical as it swings upwards due to the presence of the electric field.

(b) With S_1 closed and S_2 open, find the equilibrium angle θ.

(c) Now with S_1 open and S_2 closed, the circuit is swung from hanging straight down, $\theta = 0$, to being horizontal, $\theta = \pi/2$, in a time of $\Delta t = 5$ ms. Estimate the work required to perform this operation.

(d) The circuit is released from the horizontal with both switches open. Describe the motion of the circuit and calculate any relevant parameters necessary to backup your description. What would be the effect of closing S_2 during this motion?

Question 3

Design a spherical spacecraft which could be carried out of the solar system by the pressure of solar radiation alone. Discuss constraints on the materials used. You may assume that the craft can be initially launched from the earth using a conventional rocket so that it may start its journey already having escaped the earth's pull.

The momentum p of a photon is given by $p = E/c$ where E is the energy of the photon and c is the speed of light. The intensity of the solar radiation at the radius of the earth's orbit about the sun is given by the solar constant, $S = 1370$ W/m^2.

Link to solutions ...