CAP High School Prize Exam

April 5th 2007
9:00 – 12:00

Competitor's Information Sheet

The following information will be used to inform competitors and schools of the exam results, to determine eligibility for some subsequent competitions, and for statistical purposes. Only the marking code, to be assigned by the local examination committee, will be used to identify papers for marking.

Marking Code:

This box must be left empty.

PLEASE PRINT CLEARLY IN BLOCK LETTERS.

Family Name:________________________________ Given Name:_______________________

Home Address:____

____ Postal Code:______________

Telephone: (   )____________________ E-mail: __________________________________

School: ____ Grade:_____

Physics Teacher: ____

Date of Birth: ___________________________ Sex: Male ☐ Female ☐

Citizenship: ____ or

Immigration Status:____

For how many years have you studied in a Canadian school? ____________________________

Would you prefer the further correspondence in French or English? _______________________

Sponsored by:

Canadian Association of Physicists
Canadian Chemistry and Physics Olympiads

Canadian Association of Physicists 2007 Prize Exam

This is a three-hour exam. National ranking and prizes will be based on a student's performance on sections A, B, and C of the exam. Performance on the questions in parts A and B will be used to determine whose written work in part C will be marked for prize consideration by the CAP Exam National Committee. Part A consists of twenty multiple-choice questions; part B consists of five questions that require graphic solution. The problems in part C can also require graphing. The questions in part C have a range of difficulty. Do be careful to gather as many of the easier marks as possible before venturing into more difficult territory. If an answer to part (a) of a question is needed for part (b), and you are not able to solve part (a), assume a likely solution and attempt the rest of the question anyway. No student is expected to complete this exam and parts of each problem may be very challenging.

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

Data

Speed of light $c = 3.00\text{x}10^8$ m/s
Gravitational constant $G = 6.67\text{x}10^{-11}$ N·m²/kg²
Acceleration due to gravity $g = 9.80$ m/s²
Density of fresh water $\rho = 1.00\text{x}10^3$ kg/m³
The normal atmospheric pressure $P_0 = 1.01\text{x}10^5$Pa
Fundamental charge $e = 1.60\text{x}10^{-19}$ C
Mass of electron $m_e = 9.11\text{x}10^{-31}$ kg
Mass of proton $m_p = 1.67\text{x}\ 10^{-27}$ kg
Planck's constant $h = 6.63\text{x}10^{-34}$ J·s
Coulomb's constant $1/(4\pi\varepsilon_0) = 8.99\text{x}10^9$ N·m²/C²
Boltzmann constant $k = 1.38\text{x}10^{-23}$ J/K

Part A: Multiple Choice

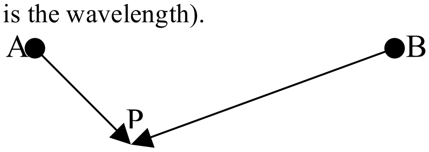
Question 1

A book is placed on a chair. Then a videocassette is placed on the book. The floor exerts a normal force:

(a) on all three;
(b) only on the book;
(c) only on the chair;
(d) upwards on the chair and downwards on the book.

Question 2

The figure shows two point sources (A and B) of coherent mechanical waves of the same wavelength. Source B emits waves that are $+\pi$ radians out of phase with the waves from source A. Source A is 3λ distant from P and source B is 5λ distant from P (λ is the wavelength).

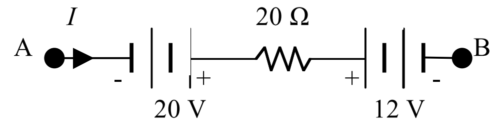


The phase difference between the waves arriving at P from A and B is

(a) 0 rad (b) $\pi/2$ rad (c) 2π rad (d) 3π rad (e) 4π rad

Question 3

What is the potential difference $V_B - V_A$ in the circuit segment below if the current $I = 1.5$ A?

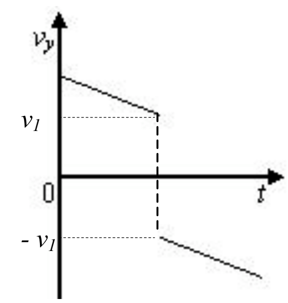


(a) +22 V (b) –22 V (c) –38 V (d) +38 V (e) +2.0 V

Question 4

The graph on the right shows a velocity versus time graph for a ball.

Which explanation best fits the motion of the ball as shown by the graph?



(a) The ball falls, is caught, and is thrown down with a greater velocity.
(b) The ball rises, hits the ceiling, and falls down.
(c) The ball falls, hits the floor, and bounces up.
(d) The ball rises, is caught, and then is thrown down.

Question 5

A light bulb A is rated at 60 W and a light bulb B is rated at 100 W. Both are designed to operate at 110 V. Which statement is correct?

(a) The 60 W bulb has a greater resistance and greater current than the 100 W bulb.
(b) The 60 W bulb has a greater resistance and smaller current than the 100 W bulb.
(c) The 60 W bulb has a smaller resistance and smaller current than the 100 W bulb.
(d) The 60 W bulb has a smaller resistance and greater current than the 100 W bulb.
(e) We need to know the resistivities of the filaments to answer this question.

Question 6

When a light ray travels between any two points, the path it takes is the one that

(a) covers the greatest distance;
(b) avoids travel in more than one medium;
(c) covers the least distance;
(d) takes the least time;
(e) is the mean between the longest and the shortest paths.

Question 7

A fountain sends water to a height of 100 metres. What must be the pressurization (above atmospheric pressure) of the water system driving the fountain? 1 ATM = 10^5 N/m².

(a) 10.8 ATM; (b) 9.80 ATM;
(c) 8.80 ATM; (d) 1.00 ATM.

Question 8

A bead of mass m, attached to a string, is pushed and starts to rotate in the vertical plane. Only the gravitaional force influences the rotation of the bead. The difference between the tension of the string when the bead is at the lowest point (T_L) and when the bead is at the upper point (T_U) is:

(a) $T_U - T_L = 2mg$;
(b) $T_U - T_L = 6mg$;
(c) $T_L - T_U = 2mg$;
(d) $T_L - T_U = 5mg$;
(e) $T_L - T_U = 6mg$.

Question 9

Two identical particles, each with a mass of 4.5 mg and charge of 30 nC, are moving directly toward each other with equal speeds of 4.0 m/s at the instant when the distance separating the two particles is equal to 25 cm. How far apart will they be from each other at the point of closest approach?

(a) 7.8 cm; (b) 9.8 cm; (c) 12 cm;
(d) 15 cm; (e) 20 cm.

Question 10

A straight wire of length L carries a current I in the positive z direction in a region where the magnetic field is uniform and specified by $B_x = 3B$, $B_y = -2B$, and $B_z = B$, where B is a constant. What is the magnitude of the magnetic force on the wire?

(a) 1.0 ILB; (b) 3.2 ILB; (c) 3.6 ILB;
(d) 4.2 ILB; (e) 5.0 ILB

Question 11

A spaceship of mass m circles a planet of mass M in a circular orbit of radius R. How much energy is required to transfer the spaceship to a circular orbit of radius $3R$?

(a) $GmM/(2R)$; (b) $GmM/(3R)$; (c) $GmM/(4R)$;
(d) $GmM/(6R)$; (e) $3GmM/(4R)$

Question 12

Three simple pendulums with strings of different lengths and bobs of different masses are pulled out from their position of equilibrium to angles of θ_1, $\theta_2 = 2\theta_1$, and $\theta_3 = 3\theta_1$, respectively. All angles θ_1, θ_2 and θ_3 are very small. The bobs are then released and start oscillating freely. Which answer better matches the results of measurements of the frequencies of the three pendulums?

(a) $f_1 = 2f_2$ and $f_1 = 3f_3$;
(b) $f_3 = 3f_1$ and $f_2 = 2f_1$;
(c) $f_1 = f_2 = f_3$;
(d) We need to know the mass of each bob to find the relationship between the frequencies;
(e) We need to know the length of each pendulum to find the relationship between the frequencies.

Question 13

The electric potential inside a charged solid spherical conductor in equilibrium:

(a) is always zero;
(b) decreases from its value at the surface to a value of zero at the centre;
(c) is constant and is equal to its value at the surface;
(d) increases from its value at the surface to a higher value at the centre.

Question 14

For which process below will the internal energy of a system NOT change?

(a) An adiabatic expansion or compression of an ideal gas;
(b) An isothermal expansion or compression of an ideal gas;
(c) An isobaric expansion or compression of an ideal gas;
(d) The freezing of a quantity of a liquid at its melting point;
(e) The evaporation of a quantity of a liquid at its boiling point.

Question 15

A diver shines an underwater searchlight at the surface of a pond whose water has an index of refraction $n = 1.33$. At what angle of incidence relative to the surface will the light be totally reflected?

(a) 41^o (b) 47^o (c) 49^o
(d) 51^o (e) 58^o

Question 16

According to the Bohr model of the atom, an electron can undergo a transition from one orbit that is closer to the nucleus to another which is farther from the nucleus, by absorbing a photon whose energy E depends on its frequency f as $E = hf$, where h is Planck's constant. An energy of 13.6 eV is needed to ionize a hydrogen atom by ejccting an electron from the lowest energy level. What is the longest wavelength of a photon that can eject the electron from the lowest energy level of the atom?

(a) 40 nm;
(b) 60 nm;
(c) 70 nm;
(d) 80 nm;
(e) 90 nm.

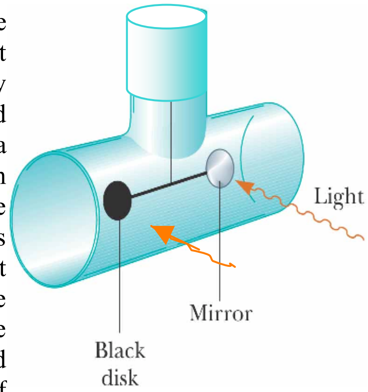
Question 17

One reason why we know that magnetic fields are not the same as electric fields is because the force they exert on a charge $+q$, is:

(a) in opposite directions in electric and magnetic fields if the charge is moving;
(b) parallel to the magnetic field and perpendicular to the electric field if the charge is moving;
(c) parallel to the electric field and perpendicular to the magnetic field if the charge is moving;
(d) zero in the electric field and nonzero in the magnetic field if the charge is not moving;

Question 18

In an experiment to prove the existence of the light pressure, two vertically oriented disks are attached as shown to the ends of a horizontal beam in an evacuated tube. The horizontal beam is suspended at its central point by a vertical wire. The surfaces of the disks are simultaneously illuminated by a parallel beam of light of high intensity.

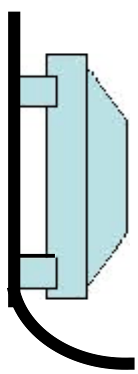


Which explanation best fits the behaviour of the two-disk system?

(a) The horizontal beam is displaced from its equilibrium position due to the equal light pressure on both discs.
(b) The horizontal beam rotates around the vertical wire with the mirror moving in the direction of light propagation and the black disk moving in the opposite direction.
(c) The horizontal beam rotates around the vertical wire with the black disk moving in the direction of light propagation and the mirror moving in the opposite direction.
(d) The experiment cannot show the existence of light pressure because light has no mass.

Question 19

You are shown a photo of a car driven on a vertical inside wall of a huge cylinder with a radius of 50 m. The coefficient of static friction between the car tires and the cylinder is $\mu_s = 0.8$. The minimum speed, at which the car can be driven like that, is:



(a) 20 km/h; (b) 70 km/h; (c) 90 km/h;
(d) 120 km/h.

Question 20

An emf may be induced in

(a) a piece of linear wire when it moves in a uniform static magnetic field;
(b) a closed loop of wire moving with a fixed orientation at a constant velocity in a non-uniform static magnetic field;
(c) a closed loop of wire moving with a fixed orientation and accelerating in a uniform static magnetic field;
(d) the cases described in (a) and (b) only;
(e) the cases described in (b) and (c) only.

Part B: Questions that require graphical solutions

Question 21

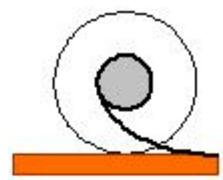
Two identical dielectric balls supported by insulating threads hang side by side, touching each other. The two balls are initially electrically neutral.
Sketch the position of the balls on their threads after one of the balls is positively charged and the other stays neutral.
Sketch the electric field lines near the balls.

Question 22

A 71-kg man stands on a spring scale in an elevator. Starting from rest, the elevator ascends, attaining its maximum speed of 1.2 m/s in 0.80 s. It travels with this constant speed for the next 2.0 seconds. The elevator then undergoes a uniform deceleration downwards (in the negative y direction) for 1.9 s and comes to rest.
Draw a diagram for the reading of the scale versus time during the motion of the elevator.

Question 23

A spool of thread on a horizontal surface may roll without slipping if someone pulls it by the free end of the thread. The spool may roll toward or away from the person who pulls the free end of the thread depending on the direction of the applied force.



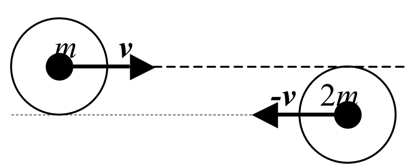
Sketch a side-view diagram of the spool of thread on the horizontal surface which shows the direction of the force applied to the free end of the thread in such a way that this force does not cause the rolling of the spool in either direction. The force belongs to the plane of the drawing.

Question 24

Consider the motion of a mass attached to a spring.
Sketch the following two graphs one below the other using the same scale for the time axis (in units of period):
1) Displacement of the mass versus time;
2) Kinetic energy of the mass versus time.

Question 25

A system consists of two ideal spheres with equal diameters that move toward each other as shown.



The spheres undergo a glancing collision.
Sketch a vector diagram for the linear momentum of each of the spheres and for the centre of mass of the system before and after the perfectly elastic collision of the spheres.

Part C: Problems

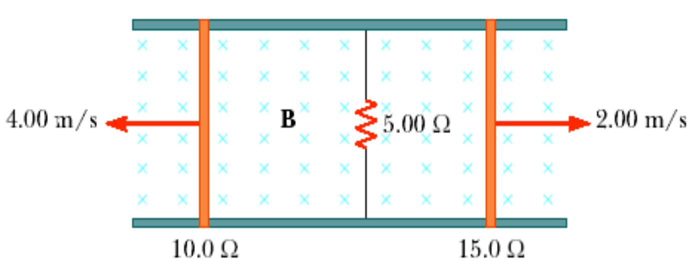
Problem 1

A student working in a laboratory has to remove a heavy box with new equipment from its initial position on the floor to the opposite wall of the room, which is d metres away. She may choose: either to pick up the box, to carry it in her hands across the room, and then to drop it on the floor in the new place; or to attach a rope to one of the corners of the box and pull the box along the floor to the new place. The mass M of the box and its contents is printed on the package. Acceleration due to gravity g, the coefficients of static and kinetic friction μ_s and μ_k for the box material and the floor, and other constants are available to the student in a handbook. After performing some calculations, the student notes that $\mu_k < \mu_s < 1$ and chooses the second method.

1) What physical quantities should the student compare to choose the proper method of moving the heavy box?
2) What parameter related to a quantity above shows an advantage for one of the two methods? Estimate this parameter for the two methods.
3) Draw a free-body diagram (i.e. a vector diagram) for the chosen method of pulling the box with the attached rope along the horizontal floor.
4) Dragging the box may be easier or harder. Express the condition that makes dragging easiest in terms of physics. Identify the parameter responsible for this condition using your free-body diagram.
5) Using the parameter found, give a numerical condition for the easiest way of moving the box by the student.

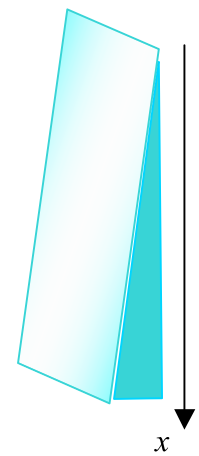
Problem 2

Two parallel rails with negligible resistance are 10.0 cm apart and are connected by a 5.00-Ω resistor. The circuit also contains two metal rods having resistances of 10.0 Ω and 15.0 Ω sliding along the rails as shown in the figure. The rods are pulled away from the resistor at constant speeds of 4.00 m/s and 2.00 m/s, respectively. A uniform magnetic field of magnitude 0.0100 T is applied perpendicular to the plane of the rails.



1) Determine the direction and the value of the current in the 5.00 Ω resistor.
2) Find the forces applied to the 10.0 Ω and the 15.0 Ω rods.
3) What is the force applied to the segment of the circuit with the 5.00 Ω resistor?
4) If the segment with the 5.00 Ω rod could slide along the rails and was released at a given time, how would this segment move (qualitatively)?

Problem 3



A soap film with an index of refraction $n = 1.33$ is contained within a rectangular wire frame. The frame is held vertically so that the film drains downwards and approximates the shape of a wedge with flat faces near the top. The thickness of the film at the very top is essentially zero. The film is viewed in reflected white light with near-normal incidence, and the first violet (λ = 420 nm) interference band is observed 3.00 cm from the top edge of the film.

1) Locate the first red (λ = 680 nm) interference band.
2) Determine the film thickness at the positions of the first violet and the first red bands.
3) What is the wedge angle of the film?