CAP High School Prize Exam

11 April 2008
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
2008 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 part A will be used to determine whose written work in parts B and 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 three 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.

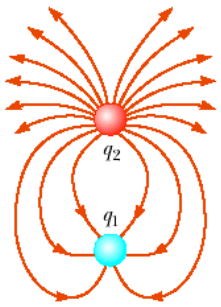
Data

Speed of light $c = 3.00\text{x}10^{8}$ m/s
Gravitational constant $G = 6.67\text{x}10^{-11}$ N·m^2/kg^2
Acceleration due to gravity $g = 9.80$ m/s^2
Density of fresh water $\rho = 1.00\text{x}10^{3}$ kg/m^3
Specific heat capacity for water $c = 4.19\text{x}10^{3}$J/(kg·K)
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·m^2/C^2
Boltzmann constant $k = 1.38\text{x}10^{-23}$ J/K

Part A: Multiple Choice

Question 1

The Figure on the right shows the electric field lines for two point objects separated by a small distance. The charges q_1 and q_2 can be identified as



(a) q_1 is positive; q_2 is negative; $q_1/q_2 = -3$;
(b) q_1 is negative; q_2 is positive; $q_1/q_2 = -3$;
(c) q_1 is positive; q_2 is negative; $q_1/q_2 = -1/3$;
(d) q_1 is negative; q_2 is positive; $q_1/q_2 = -1/3$;
(e) q_1 is zero with charges redistributed over the surface of the object *1* due to electrostatic induction; q_2 is positive.

Question 2

As a simple pendulum swings back and forth, the forces acting on the suspended object may produce positive work, negative work or produce no work. Which of the forces if any from the listed three below does no work on the pendulum?
(a) Tension.
(b) Air resistance.
(c) Gravitational force.
(d) All the forces above do no work on the pendulum.
(e) All the forces above do work on the pendulum.

Question 3

A baseball bat is made of wood of uniform density. The bat is cut at the location of its centre of mass, as shown. Which of the following is true?
(a) The piece on the right has the smaller mass;
(b) The piece on the left has the smaller mass;
(c) Both pieces have the same mass;
(d) Impossible to determine without knowledge of the wood density.

Question 4

A section of a hollow pipe and a solid cylinder have the same radius, mass and length. They both rotate about their long central axes with the same angular speed. Which of the following is true?
(a) The pipe has a higher rotational kinetic energy.
(b) The solid cylinder has a higher rotational kinetic energy.
(c) They have the same rotational kinetic energy.
(d) Impossible to determine without numerical data for radii, masses and lengths of the pipe and cylinder.

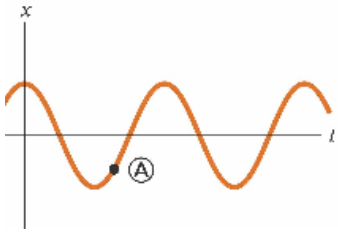
Question 5

In a comet-Sun system, the position of the comet closest to the Sun is called perihelion, and the position of the comet farthest from the Sun is called aphelion. The two quantities that both have their highest values when the comet is in perihelion are:
(a) the acceleration and the potential energy of the comet;
(b) the speed and the potential energy of the comet-Sun system;
(c) the speed and the acceleration of the comet;
(d) the acceleration and the total energy of the comet-Sun system.

Question 6

When an object is at point A on the graph of a simple harmonic motion below, what are respectively, its velocity and acceleration?

(a) both positive;
(b) both negative;
(c) positive and zero;
(d) positive and negative;
(e) negative and positive.



Question 7

Does the kinetic energy of an electron have an upper limit?

(a) Yes, $m_e c^2$.
(b) Yes, ½ $m_e c^2$.
(c) Yes, with another value.
(d) No.

Question 8

When you receive a chest x-ray at the hospital, the x-rays pass through a set of parallel ribs in your chest. Do your ribs act as a diffraction grating for the X-rays?

(a) Yes. They produce diffracted beams that can be observed separately.
(b) Not to a measurable extent. The ribs are too far apart.
(c) Essentially not. The ribs are too close together.
(d) Essentially not. The ribs are too few in number.
(e) Absolutely not. X-rays cannot diffract.

Question 9

A certain battery has some internal resistance. Can the potential difference across the terminals of the battery be equal to its *emf*?

(a) No.
(b) Yes, if the battery is absorbing energy by electrical transmission.
(c) Yes, if more than one wire is connected to each terminal.
(d)Yes, if the current in the battery is zero.

Question 10

A long solenoid with closely spaced turns carries electric current. Each turn of wire exerts:

(a) an attractive force on the next adjacent turn;
(b) a repulsive force on the next adjacent turn;
(c) zero force on the next adjacent turn; or
(d) either an attractive or a repulsive force on the next adjacent turn, depending on the direction of current in solenoid?

Question 11

An apple is held completely submerged just below the surface of a container of water. The apple is then moved to a deeper point in the water. Compared with the force needed to hold the apple just below the surface, what is the force needed to hold it at a deeper point?

(a) larger;
(b) essentially the same;
(c) smaller;
(d) impossible to determine.

Question 12

A small source radiates an electromagnetic wave with a single frequency into vacuum, equally in all directions. Indicate the pair of quantities that are decreasing as the wave moves away from the source:

(a) the frequency of the wave and an amplitude of electric field;
(b) the amplitude of the electric field and the intensity of the wave;
(c) the frequency and the intensity of the wave;
(d) the speed of propagation and the wavelength;

Question 13

Two identical balls with completely smooth surfaces are moving uniformly in free space without rotation. At some moment, they undergo a perfectly elastic glancing collision. After the collision, the angle between the two vectors of velocities is

(a) 30^o
(b) 45^o
(c) 90^o
(d) Impossible to answer without knowledge of the angle between the two velocities before the collision.

Question 14

Car batteries are often rated in ampere-hours. Does this information designate the amount of

(a) potential that the battery can supply;
(b) power;
(c) charge;
(d) energy?

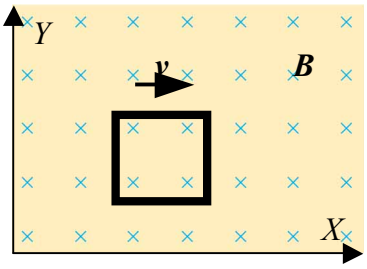
Question 15

A laser beam travels from glass into air and strikes normally the smooth interface between the two media. In the air

(a) the light travels with a lower speed normally to the interface;
(b) the light travels with a higher speed normally to the interface;
(c) the light travels with unchanged speed but bends away from the normal;
(d) the light travels with a higher speed and bends away from the normal;
(e) the light travels with a lower speed and bends away from the normal.

Question 16
If only one external force acts on an object,
(a) it always changes the kinetic energy of the object;
(b) it always changes the speed of the object;
(c) it always changes the momentum of the object.

Question 17
A square conductive frame is moving in the vertical *YX* plane at a constant velocity ***v*** through a region of uniform magnetic field ***B*** directed perpendicular to the plane of the frame as shown in the figure. Does charge separation occur in the frame?



(a) Yes, with the top positive.
(b) Yes, with the top negative.
(c) No.
(d) Yes, with the left side negative.
(e) Yes, with the left side positive.

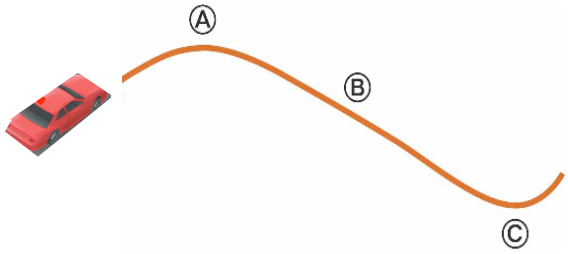
Question 18
A person spear-fishing from a boat sees a stationary fish a few meters away in a direction about 30° below the horizontal. The index of refraction of the water is 1.34. Assume the dense spear does not change direction when it enters the water. To spear the fish, the person should
(a) aim above where he sees the fish;
(b) aim precisely at the fish; or
(c) aim below the fish?

Question 19
A spacecraft built in the shape of a sphere moves past an observer on the Earth with a speed of 0.5c. Approximately what shape does the observer measure for the spacecraft as it goes by?
(a) A sphere.
(b) A cigar shape, elongated along the direction of motion.
(c) A round ”pillow” shape, flattened along the direction of motion.
(d) A conical shape, pointing in the direction of motion.

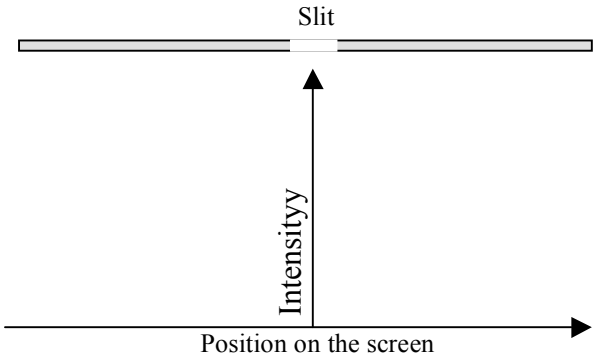
Question 20
One litre of water in a light thin-walled vessel is heated up under atmospheric pressure by an electric heater with unknown power rating. Initially the temperature of the water is 20°C. After the temperature becomes 60°C, it stops increasing, while the heater is still on. As the heater is unable to boil water, it is turned off. During the first 20 seconds the water becomes 2 degrees cooler.
Estimate the power output of the heater.
(a) 8.40 W.
(b) 420 W.
(c) 1260 W.
(d) 8400 W.

Part B: Questions that require graphical solutions

Question 1
A car accelerates uniformly along a curved horizontal road, moving from left toward right, as it is seen from a helicopter. Draw
(I) the vectors representing the forces exerted by the road on the car at points A and B;
(II) the vector of velocity at point C.



Question 2
Single-slit diffraction is observed with an interference pattern on a screen behind a slit for a red light source. The red light source is then replaced by a violet light source of same intensity, without any changes to distances and the slit width. Use the “Intensity/Position” system of coordinates as on the Figure below, to sketch the interference pattern on the screen for the two sources of light. If you think that the patterns are identical, show just one pattern. If you think that the two sources produce different patterns on the screen, make it clear which pattern corresponds to a given colour



Question 3

A skydiver jumps out of a plane at an altitude of 2000 m and begins her descent. At 1500 m, the skydiver reaches her terminal speed of 55 m/s. When the skydiver descends to a height of 500 m from the ground, she deploys her parachute which rapidly slows her down to 5 m/s to ensure a safe landing. Qualitatively, sketch the (vertical) speed of the skydiver as a function of height above ground starting just after she jumps out of the plane and finishing just before she lands.

Part C: Problems

Problem 1

A stepladder of negligible weight is constructed as shown in Figure 1C. A painter of mass 70.0 kg stands on the ladder 3.00 m from the bottom. Assuming the floor is frictionless, find

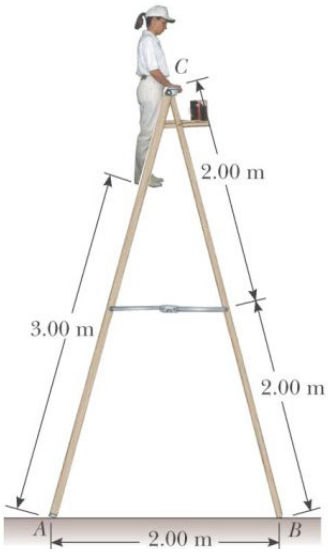


Fig.1C

(a) the tension in the horizontal bar connecting the two halves of the ladder,
(b) the normal forces at *A* and *B*, and
(c) the components of the reaction force at the single hinge *C* that the left half of the ladder exerts on the right half.

Problem 2

Two horizontal metal plates, each 100 mm square, are aligned 10.0 mm apart, with one above the other. They are given equal-magnitude charges of opposite sign so that a uniform downward electric field of 2 000 N/C exists in the region between them. A particle of mass 2.00×10^{-16} kg and with a positive charge of 1.00×10^{-6} C leaves the centre of the bottom negative plate with an initial speed of 1.00×10^{5} m/s at an angle of 37.0° above the horizontal.

(a) Find the trajectory of the particle.
(b) Which plate does it strike?
(c) Where does it strike, relative to its starting point?

Problem 3

In the arrangement shown in Figure 3C, an object is hung from a string (with linear mass density μ =0.00200 kg/m) that passes over a light pulley. The string is connected to a vibrator (of constant frequency *f*), and the length of the string between point *P* and the pulley is *L* = 2.00 m. When

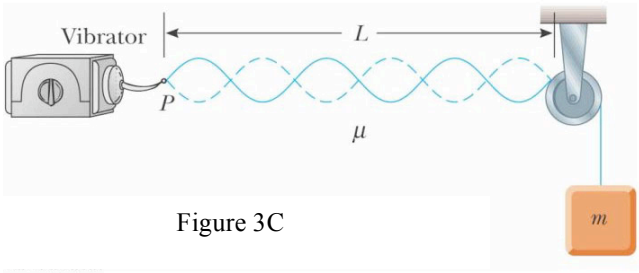


Figure 3C

the mass *m* of the object is either 16.0 kg or 25.0 kg, standing waves are observed; however, no standing waves are observed with any mass between these values. The speed of a transverse wave in a string experiencing the tension *T*, is given by: $v = \sqrt{T/\mu}$.

(a) What is the frequency of the vibrator?
(b) What is the total number of nodes observed along the compound string at this frequency, excluding the nodes at the vibrator and the pulley?
(c) What is the largest object mass for which standing waves could be observed?