

CAP High School Prize Exam

7 April 2006

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: _____

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 2006 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. Part A consists of twenty multiple-choice questions; part B consists of five questions that require graphic solutions. The problems in part C can also require graphing.

Performance on 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. 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 $c = 3.00 \times 10^8$ m/s
 Gravitational constant $G = 6.67 \times 10^{-11}$ N·m²/kg²
 Acceleration due to gravity $g = 9.80$ m/s²
 Fundamental charge $e = 1.60 \times 10^{-19}$ C
 Mass of electron $m_e = 9.11 \times 10^{-31}$ kg
 Mass of proton $m_p = 1.67 \times 10^{-27}$ kg
 Planck's constant $h = 6.63 \times 10^{-34}$ J·s
 Coulomb's constant $1/(4\pi\epsilon_0) = 8.99 \times 10^9$ N·m²/C²
 Boltzmann constant $k = 1.38 \times 10^{-23}$ J/K

Part A: Multiple Choice

Question 1

A uniform meter stick is supported on a fulcrum at the 25-cm mark. A 0.50-kg object is hung from the 0-cm end of the meter stick, and the stick is balanced horizontally. The mass of the meter stick is:

- (a) 0.25 kg; (b) 0.50 kg;
 (c) 0.75 kg; (d) 0.75 kg;

Question 2

The radius of the Earth is $6.37 \cdot 10^6$ m. Approximately how fast is a person on the Equator moving due to the Earth rotation?

- (a) 5 m/s
 (b) 50 m/s
 (c) 500 m/s
 (d) 5000 m/s

Question 3

In a certain region of space, the electric field is zero. From this we can conclude that the electric potential in this region is:

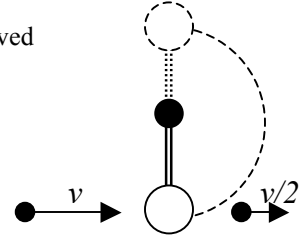
- (a) constant; (b) zero;
 (c) positive; (d) negative;

Question 4

A bullet of mass m and speed v hits a pendulum bob of mass M at time t_1 , and passes completely through the bob. The bullet emerges at time t_2 with a speed of $v/2$. The pendulum bob is suspended by a stiff rod of length l and negligible mass. After the collision, the bob can barely swing through a complete vertical circle. At time t_3 , the bob reaches the highest position.

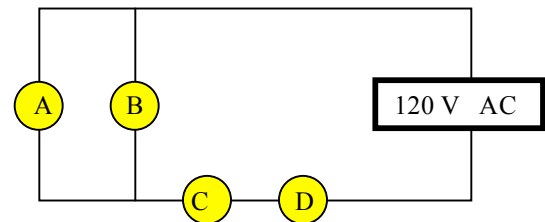
What quantities are conserved in this process?

- (a) Total kinetic energy of the bob and the bullet during the time interval $\Delta t = t_2 - t_1$.
 (b) Total momentum of the bob and the bullet during the time interval $\Delta t = t_2 - t_1$.
 (c) Total mechanical energy of the bob and the bullet during the time interval $t_3 - t_1$.
 (d) Momentum of the bob after t_2 .



Question 5

The diagram shows a circuit with four identical light bulbs.



When we remove bulb A from the circuit, the light intensity of bulb C:

- (a) remains the same;
 (b) increases;
 (c) decreases;
 (d) becomes zero.

Question 6

The amplitude of an electromagnetic wave in vacuum is doubled with no other changes made to the wave. As a result of this doubling of the amplitude, which of the following statements is correct?

- (a) The speed of propagation of the wave changes.
 (b) The frequency of the wave changes.
 (c) All of the above are true.
 (d) None of the above is true.

Question 7

Two objects are initially at rest on a frictionless surface. Object 1 has a greater mass than object 2. The same constant force starts to act on each object. The force is removed from each object after it accelerates over a distance d . After the force is removed from both objects, which statement is correct (p: momentum; K: kinetic energy)?

- (a) $p_1 < p_2$; (b) $p_1 > p_2$; (c) $K_1 > K_2$; (d) $K_1 < K_2$.

Question 8

A dart is loaded into a spring-loaded toy dart gun by pushing the spring in by a distance d . For the next loading, the spring is compressed a distance $2d$. How much faster does the second dart leave the gun compared to the first?

- (a) four times as fast;
- (b) two times as fast;
- (c) the same;
- (d) half as fast;
- (e) one-fourth as fast.

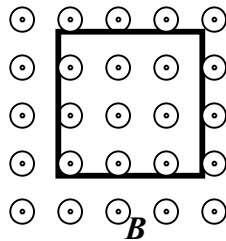
Question 9

One of two parallel metallic plates is uniformly charged with charge $+q$, and the other one is charged with charge $-q$. In this case, the electric field between them is E . When the negatively charged plate is discharged then recharged with a positive charge $4q$, the electric field between the plates becomes:

- (a) 0;
- (b) $1.5 E$;
- (c) $2.5 E$;
- (d) $3E$;
- (e) $5E$.

Question 10

A uniform magnetic field B is directed out of the page. A metallic wire has the shape of a square frame and is placed in the field as shown. While the shape of the wire is steadily transformed into a circle in the same plane, the current in the frame:



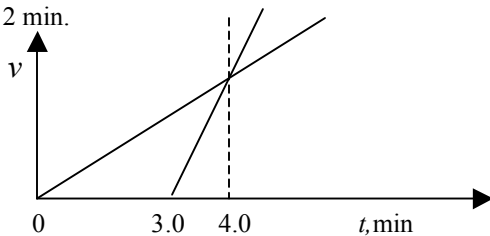
- (a) is directed clockwise;
- (b) does not appear;
- (c) is directed counterclockwise.

Question 11

The drawing shows velocity (v) versus time (t) graphs for two cyclists moving along the same straight segment of a highway from the same point. The second cyclist starts moving at $t = 3.0$ min.

At what time do the two cyclists meet?

- (a) 4.0 min;
- (b) 6.0 min;
- (c) 12 min.

**Question 12**

Two solid spheres manufactured of the same material freely fall down in the air. One sphere has a diameter twice as large as the other. The force due to air resistance is proportional to the cross-sectional area of a moving object

and is a quadratic function of the speed of an object. Some time after the beginning of motion in the presence of air resistance, the velocity of each sphere becomes constant. It is called the terminal velocity. The ratio of terminal velocities of the spheres $v_{\text{big}}/v_{\text{small}}$ is:

- (a) 2;
- (b) $\sqrt{2}$;
- (c) $\frac{1}{2}$;
- (d) $\frac{1}{\sqrt{2}}$

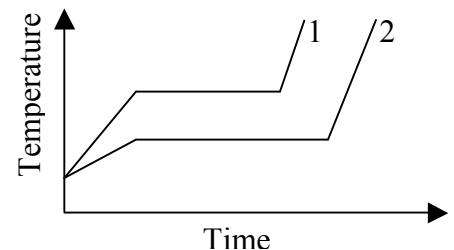
Question 13

Astronauts are weightless in orbit because:

- (a) they are beyond the pull of gravity;
- (b) they travel in the accelerated frame of reference where fictitious centrifugal force is equal to centripetal force, and the net force on an astronaut is zero;
- (c) they are in free fall together with their spacecraft;
- (d) of another cause.

Question 14

Two solid objects of the same mass are supplied with heat at the same rate $\Delta Q / \Delta t$. The temperature of the first object with latent heat L_1 and specific heat capacity c_1 changes according to graph 1 on the diagram. The temperature of the second object with latent heat L_2 and specific heat capacity c_2 changes according to graph 2 on the diagram.

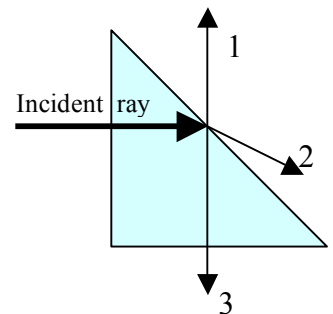


Based on what is shown on the graph, the latent heats L_1 and L_2 , and the specific heat capacities c_1 and c_2 in solid state obey which of the following relationships:

- (a) $L_1 > L_2$; $c_1 < c_2$;
- (b) $L_1 < L_2$; $c_1 < c_2$;
- (c) There is not enough information to determine these relations;
- (d) $L_1 > L_2$; $c_1 > c_2$;
- (e) $L_1 < L_2$; $c_1 > c_2$.

Question 15

A light ray strikes a prism as shown in the drawing. The angles of the prism are 90° , 45° , and 45° . The critical angle of the prism material is 49° . What rays are the possible continuations of the incident ray?



- (a) The ray 1 only.
- (b) The ray 2 only.
- (c) The ray 3 only.
- (d) Both rays 1 and 3.
- (e) Both rays 2 and 3.

Question 16

You stand on a platform at a train station and listen to a train horn as the train approaches the station at a constant velocity. While the train approaches, but before it arrives, you hear:

- (a) the intensity and the frequency of the sound both increasing;
- (b) the intensity and the frequency of the sound both decreasing;
- (c) the intensity increasing and the frequency decreasing;
- (d) the intensity decreasing and the frequency increasing;
- (e) the intensity increasing and the frequency remaining the same;

Question 17

A linear conductor with current I_1 is placed along the axis of a circular conductor, which carries current I_2 .

The magnetic force acting on each of the conductors is:

- (a) zero;
- (b) directly proportional to the product of currents I_1 and I_2 , and inversely proportional to the radius of the circular conductor;
- (c) directly proportional to the product of currents I_1 and I_2 , inversely proportional to the square of the radius of the circular conductor;
- (d) directly proportional to the product of current I_1 , current I_2 , and the area of a circular conductor;

Question 18

An aquarium is filled with water. The lateral wall of the aquarium is 40 cm long and 30 cm high. Using 10 m/s^2 for the acceleration due to gravity, and 1 g/cm^3 for the density of water, the force on the lateral wall of the aquarium is:

- (a) 36 N;
- (b) 90 N;
- (c) 180 N;
- (d) 1500 N.

Question 19

A satellite is moved from one circular orbit around the earth, to another of lesser radius. Which of the following is true?

- (a) The kinetic energy increases and the potential energy increases;
- (b) The kinetic energy increases, and the potential energy decreases;
- (c) The kinetic energy decreases and the potential energy decreases;
- (d) The kinetic energy decreases and the potential energy increases.

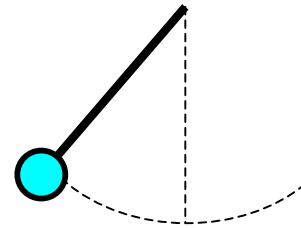
Question 20

A point particle carries a positive charge $+q$ and is maintained at a distance h above a large conductive uncharged plate. The electric force of interaction between the charge and the plate is **best** described as:

- (a) zero force;
- (b) an attractive force proportional to q/h^2 ;
- (c) an attractive force proportional to q^2/h^2 ;
- (d) an attractive force proportional to $q^2/4h^2$;
- (e) a repulsive force proportional to q^2/h^2 .

Part B: Problems that require graphic solutions**Question 21**

A heavy pendulum bob is swinging back and forth when the string, supporting it, suddenly breaks. Ignoring the mass of the string and air resistance, draw the path of the subsequent motion of the bob if the string breaks when the bob is at its highest point.

**Question 22**

A long vertical tube with a weightless movable piston inside has its lower end under water. The tube is motionless throughout the experiment. The cross-sectional area of the piston is A . The initial position of the piston is just over the surface of the water. Then it is slowly moved upwards. Sketch a graph of the force necessary to lift the piston as a function of the height of the piston.

Question 23

On the same graph, draw the following two functions: 1) kinetic energy versus speed of a particle according to classical mechanics and 2) the same function for Einstein's relativistic theory.

Question 24

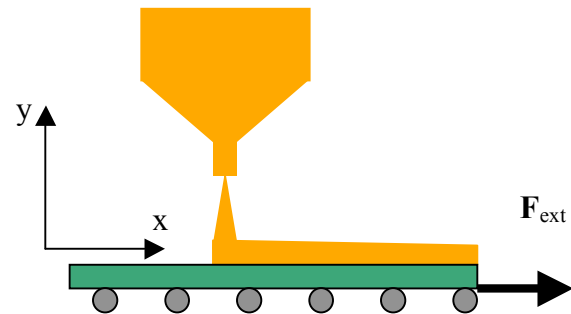
An electron is moving at a constant velocity in a region of space with a uniform electric field of $1.0 \cdot 10^3$ N/C and a uniform magnetic field of $1.0 \cdot 10^{-3}$ T. The electric field has only an x-component while the magnetic field has only a y-component.

Sketch a vector diagram for the velocity of the electron, the magnetic field, and the electric field in the Cartesian system of coordinates.

Question 25

A brick is on an incline whose angle of inclination can be changed from 0 to 90 degrees.

Sketch a graph of the force of friction acting on the brick versus the angle of inclination in the given range.

Part C: Problems**Problem 1**

Sand from a stationary hopper falls onto a moving conveyor belt at a rate of 5.00 kg/s as shown above. The conveyor belt is supported by frictionless rollers and moves at a constant speed of 0.75 m/s under the action of a constant horizontal external force F_{ext} supplied by the motor that drives the belt. Find:

- 1) the force of friction exerted by the belt on the sand;
- 2) the external force F_{ext} ;
- 3) the work done by F_{ext} in 1 s;
- 4) the kinetic energy acquired by the falling sand each second due to the change in its horizontal motion;
- 5) compare and analyse the answers to 3) and 4).

Problem 2

A source of electric power with electromotive force E and internal resistance r , is connected to a resistor.

- 1) Find the power delivered to the resistor as a function of the resistance of the resistor.
- 2) Find the power produced by the source as a function of the resistance of the resistor.
- 3) Sketch graphs of these two functions.
- 4) Treating the efficiency of the source as the ratio of power consumed to power produced by the source, find the efficiency of the source of electric power as a function of the resistance of the resistor and sketch the graph of this function.
- 5) Find the resistance of the resistor that corresponds to the maximum power delivered to the resistor, and calculate the efficiency for this resistance.

Problem 3

A point source of light is moving uniformly along a straight line, which intersects the optical axis of a converging lens under a small angle α at a distance $2F$ from the lens with a focal distance F . The speed of the source of light is v_0 .

- i. Draw the lens, the trajectory of the source of light, and the trajectory of its image produced by the lens.
- ii. Draw the vector diagram for the velocity of the source of light, the velocity of the image, and the relative velocity of the image with respect to the source.
- iii. Determine the minimum relative speed of the image of the source of light with respect to the source.