CAP High School Prize Exam

April 9th, 2013
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: (   ) ______________________ Email: ______________________

School: ______________________ Grade: ______________________

Physics Teacher: ____

Date of Birth: ______________________ Sex: Male ☐ Female ☐

Citizenship: ____

If not a Canadian citizen, what is your Immigration Status? ______________________

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

Would you prefer further correspondence in French or English? ______________________

Sponsored by:

Canadian Association of Physicists,
Canadian Physics Olympiad,

The University of British Columbia,
Department of Physics and Astronomy.

Canadian Association of Physicists
2013 Prize Exam

This is a three-hour exam. National ranking and prizes will be based on students' performance on sections A and B of the exam. Performance on the questions in part A will be used to determine whose written work in part B will be marked for prize consideration by the CAP Exam National Committee. Part A consists of twenty-five multiple-choice questions. The questions in part B span a range of difficulties, and may require graphing. 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.

Non-programmable calculators may be used. Please be careful to answer the multiple-choice questions ***on the answer 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.

Notice: Full marks will be given to a student who provides any full correct solution to the long problems. Partial marks will be given for partial solutions. There are no penalties for incorrect answers. The questions are not of equal difficulty. Remember we are challenging the best physics students in Canada; it is possible that even the best papers may not achieve an overall score of 80%. This is meant to be tough!

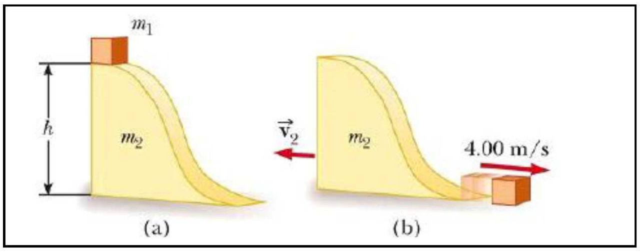
Data

Speed of light $c = 3.00 \times 10^8\,\mathrm{m/s}$
Gravitational constant $G = 6.67 \times 10^{-11}\,\mathrm{N \cdot m^2/kg^2}$
Acceleration due to gravity $g = 9.80\,\mathrm{m/s^2}$
Normal atmospheric pressure $P_0 = 1.01 \times 10^5\,\mathrm{Pa}$
Density of fresh water $\rho = 1.00 \times 10^3\,\mathrm{kg/m^3}$
Specific heat of water $C_w = 4186\,\mathrm{J/(kg \cdot K)}$
Specific heat of ice $C_i = 2050\,\mathrm{J/(kg \cdot K)}$
Latent heat of water $L_w = 2260\,\mathrm{kJ/kg}$
Latent heat of ice $L_i = 334\,\mathrm{kJ/kg}$
Density of ice $\rho_i = 916\,\mathrm{kg/m^3}$
Fundamental charge $e = 1.60 \times 10^{-19}\,\mathrm{C}$
Mass of electron $m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$
Mass of proton $m_p = 1.67 \times 10^{-27}\,\mathrm{kg}$
Planck's constant $h = 6.63 \times 10^{-34}\,\mathrm{Js}$
Coulomb's constant $1/(4\pi\epsilon_0) = 8.99 \times 10^9\,\mathrm{N \cdot m^2/C^2}$
Boltzmann's constant $k = 1.38 \times 10^{-23}\,\mathrm{J/K}$
A.U. Astronomical Unit $= 1.49598 \times 10^{11}\,\mathrm{m}$: The approximate distance from the Sun to the Earth.
Radius of the Earth $R_E = 6.371 \times 10^6\,\mathrm{m}$
Radius of the Sun $R_S = 6.96 \times 10^8\,\mathrm{m}$

Part A: Multiple Choice

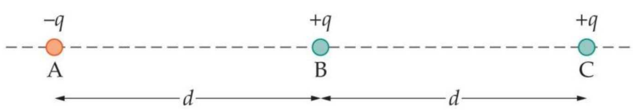
Each multiple choice question is worth 1 point.

Question 1
A small block of mass m_1 is released from rest at the top of a curve-shaped, frictionless wedge of mass m_2 which sits on a frictionless horizontal surface as shown. When the block leaves the wedge its velocity is measured to be 4.00 m/s to the right as shown in the figure. If the mass of the block is doubled to become $2m_1$, what can be said about the speed with which it leaves the wedge?



a) Its speed is less than 4.00 m/s
b) Its speed is equal to 4.00 m/s
c) Its speed is greater than 4.00 m/s
d) Not enough information is given.

Question 2
Consider the electric charges A, B, C shown in the figure below, where q is a positive number. Which answer correctly describes the magnitude of the net force experienced by the charges?



a) $F_A > F_B > F_C$
b) $F_A > F_C > F_B$
c) $F_B > F_A > F_C$
d) $F_A = F_B = F_C$
e) $F_A > F_B = F_C$

Question 3
A long, straight wire carries a current that decreases linearly with time. What is the direction of the induced electric field outside the wire?

a) Parallel to the current in the wire, in the same direction.
b) Parallel to the current in the wire, in the opposite direction.
c) Pointing radially outward from the wire.
d) Pointing radially inward toward the wire.
e) There is no induced electric field outside the wire.

Question 4
A car driven at a constant speed turns left. Which force makes the car turn?

a) The force of friction, directed towards the left.
b) The force of friction, directed towards the right.
c) The force with which the driver is turning the steering wheel, directed towards the left.
d) The force with which the driver is turning the steering wheel, directed towards the right.

Question 5
A cyclist stops pedaling at a velocity $v = 36$ km/h and notices that her bike keeps moving for $d = 500$ m before it stops. The total mass of the bike, the biker and her camping equipment is $m = 100$ kg. What is the average combined force on the bicycle due to friction and drag?

a) 10 N
b) 20 N
c) 130 N
d) 260 N

Question 6
A child is swinging to and fro on a playground swing. At the instant the chains of the swing are vertical, what is the direction of the child's acceleration?

a) Downwards.
b) Upwards.
c) In the direction of motion.
d) Opposite to the direction of motion.
e) At that moment, the acceleration is zero.

Question 7
A bullet of mass 5 g is accelerated in a rifle barrel with an approximately constant force of 2500 N. The mass of the rifle is 5 kg. What is the force pushing the rifle back?

a) 2.5 N
b) 2 500 N
c) 2 500 000 N
d) 0 N

Question 8
Two balls of different masses collide head-on. After the collision, the balls remain at rest, and no external forces act on them. Which statement is true about the speeds of the balls before the collision?

a) They must have been different, and the collision was inelastic.
b) They must have been different, and the collision was elastic.
c) They must have been identical, and the collision was inelastic.
d) They must have been identical, and the collision was elastic.
e) No combination of speed values could have caused both balls to stop after the collision.

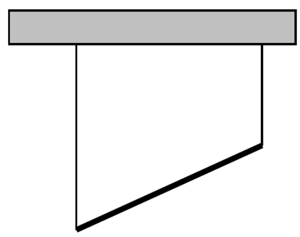
Question 9

A Ferris wheel is turning about a horizontal axis through its center. The linear speed of a passenger sitting on the rim is constant. Which one of the following sentences about the passenger's acceleration is correct?

a) Its magnitude at the highest point is higher than at the lowest point, and it is downwards at both points.
b) Both its magnitude and direction are the same at the highest and at the lowest points.
c) Its magnitude is the same at the highest and at the lowest points, but the directions are opposite.
d) Its magnitude at the highest point is smaller than at the lowest point, and it is downwards at both points.

Question 10

A uniform rod is suspended on two thin strings as shown below. Which string has a larger tension force?



a) The right one
b) The left one
c) The tension force is the same on both
d) It depends on the angle

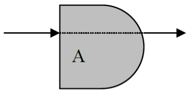
Question 11

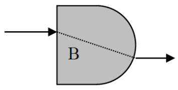
Two point charges $-2Q$ and $+Q$ are placed on the x-axis with $-2Q$ at $x = 0$ and $+Q$ at $x = a$. Which of the following statements is true?

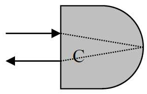
a) There is no point on the x-axis where the electric field is zero.
b) There is a point on the x-axis, at $x < 0$, where the electric field is zero.
c) There is a point on the x-axis, between the charges ($0 < x < a$), where the electric field is zero.
d) There is a point on the x-axis, at $x > a$, where the electric field is zero.

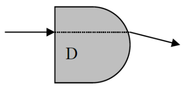
Question 12

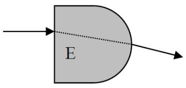
In a lab experiment, a laser beam hits a semicircular glass object off the centre axis. The ray enters perpendicularly to the surface, and the environment is air. Which ray diagram is correct?

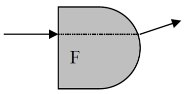
a) 

b) 

c) 

d) 

e) 

f) 

Question 13

You put two identical ice cubes on plates of different materials. One cube is put on an aluminum plate, and the other on a glass plate. Both plates have been in the room for a long time prior to the experiment. You notice that the ice melts faster on the metal plate. Why?

a) The ice is in thermal equilibrium with the plastic plate, but not with the metal plate.
b) The metal plate conducts heat to the ice more rapidly than the plastic plate.
c) The metal plate holds more heat than the plastic plate.
d) The metal plate was warmer than the plastic plate initially.

Question 14

Two black objects of the same diameter, a sphere and a flat disk, are placed in a parallel beam of light. The plane of the disk is perpendicular to the beam. What can be said about the force acting on them?

a) The force is zero.
b) The force is larger on the disk than on the sphere.
c) The force is larger on the sphere than on the disk.
d) The force is the same on both objects.

Question 15

Adrianne has a device that emits photons with a wavelength of $\lambda = 1.498$ km. Kwan has a similar device that emits photons at a frequency of $f = 201$ kHz. Whose device emits photons in air at the highest frequency?

a) Adrianne's
b) Kwan's
c) The frequencies are the same.
d) There is not enough information to compare.

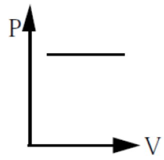
Question 16

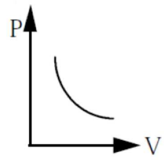
A girl sitting on a floating mattress in a small pool holds a model of a motorboat in her hands. When she puts it in the water to start driving it with her remote control, what happens to the water level in the pool?

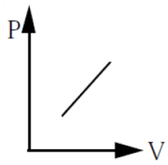
a) It rises by a small amount.
b) It drops by a small amount.
c) It stays the same.
d) The qualitative result depends on the weight of the model boat.

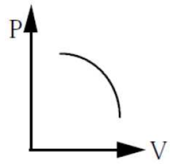
Question 17

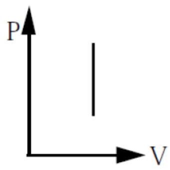
Which of the accompanying $P-V$ diagrams best represents an isothermal process, that is a process occurring at constant temperature?

a) 

b) 

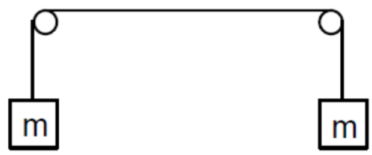
c) 

d) 

e) 

Question 18

Two identical objects of mass m are connected to a massless string which is hung over two frictionless pulleys as shown below. If everything is at rest, what is the tension in the cord?



a) Less than mg.
b) Exactly mg.
c) More than mg, but less than $2mg$.
d) Exactly $2mg$.
e) More than $2mg$.

Question 19

Car A and car B are both traveling down a straight highway at 90 km/h. Car A is only 6.0 meters behind car B. The driver of car B brakes, slowing down with a constant deceleration of $2.0\,\mathrm{m/s^2}$. After 1.2 seconds, the driver of car A begins to brake, also at $2.0\,\mathrm{m/s^2}$, but this is insufficient and the cars eventually collide, both still moving forward. What is the relative velocity of the two cars at the moment of the collision?

a) 2.4 m/s
b) 5.0 m/s
c) 9.5 m/s
d) 21 m/s
e) 24 m/s

Question 20

Two interfering waves have the same wavelength, frequency, and amplitude. They are traveling in the same direction but are 90 degrees out of phase. Compared to the individual waves, what can be said about the resultant wave?

a) It will have the same amplitude and velocity, but a different wavelength.
b) It will have the same amplitude and wavelength, but a different velocity.
c) It will have the same wavelength and velocity, but a different amplitude.
d) It will have the same amplitude and frequency, but a different velocity.
e) It will have the same frequency and velocity, but a different wavelength.

Question 21

A spinning ice skater has an initial kinetic energy $\frac{1}{2}I\omega^2$. She pulls in her outstretched arms, decreasing her moment of inertia to $\frac{1}{4}I$. What is her new angular speed?

a) $\omega/4$
b) $\omega/2$
c) ω
d) 2ω
e) 4ω

Question 22

A ball of mass m is thrown vertically upward. Instead of neglecting air resistance, assume that the force of air resistance has a magnitude proportional to the ball's velocity, but pointing in the opposite direction. What is the ball's acceleration at the highest point?

a) 0
b) Less than g.
c) g
d) Greater than g.

Question 23

A hypothetical planet has density ρ, radius R, and surface gravitational acceleration g. What would be the acceleration due to gravity at the surface of a planet with double the radius, and the same planetary density?

a) $4g$
b) $2g$
c) g
d) $g/2$
e) $g/4$

Question 24

You are given two lenses placed close together: a converging lens with focal length +10 cm, and a diverging lens with focal length −20 cm. Which of the following would produce a virtual image that is larger than the object?

a) Placing the object 5 cm from the converging lens.
b) Placing the object 15 cm from the converging lens.
c) Placing the object 25 cm from the converging lens.
d) Placing the object 15 cm from the diverging lens.
e) Placing the object 25 cm from the diverging lens.

Question 25

An electromagnetic wave is propagating in vacuum in the positive z direction. At an instant when its magnetic field B at a certain position is in the positive x direction and getting stronger, what happens to its electric field E at that same position?

a) E is in the positive x direction and getting weaker.
b) E is in the negative x direction and getting stronger.
c) E is in the positive y direction and getting weaker.
d) E is in the negative y direction and getting stronger.
e) E is zero.

Part B: Problems

Problem 1

A light emitting diode (LED) is connected in series with a super capacitor of capacity 3000 F and internal resistance $\sim$ 1 mΩ, and a microprocessor-controlled resistor. The capacitor is charged to 5 V. The LED requires constant current of 800 mA. At this current, the voltage drop over the LED is 2.7 V.

a) What should be the dependence of the variable resistor on time for the current to remain constant?

b) What should be the initial value of the resistor? Does the value of the resistor stabilize after some time, and if so, to which resistance?

c) How long can the LED operate at full brightness before the capacitor needs to be recharged?

Problem 2

A light spring with a force constant of 3.85 N/m is compressed by 8.00 cm and held between two blocks. The block on the left has a mass of 250 g, while the block on the right has a mass of 500 g. Both blocks are initially held at rest on a horizontal surface, and are then released simultaneously so that the spring pushes them apart.

What is the maximum velocity each block attains if the coefficient of kinetic friction between each block and the surface is 0.100 and the coefficient of static friction is 0.120?

Problem 3

The luminosity of a star is defined as the energy it emits per unit time. We know from astronomical observations that the luminosity L of the stars that have a mass $M < 10M_S$ is approximately related to their mass as:

$$\frac{L}{L_S} = (\frac{M}{M_S})^{3.5} \tag{1}$$

where L_S and M_S are the luminosity and mass of the Sun.

Furthermore, we know from Einstein's theory of relativity that the energy released from converting a mass M into energy is given by $E = Mc^2$. In this problem, we assume that all stars burn almost the same fraction of their mass during their active life.

a) If the fraction of the mass converted into energy is $\alpha \ll 1$, first find an expression for the lifetime of a star in terms of its mass, luminosity, α and physical constants.

b) Using the luminosity-mass equation, find the lifetime of a star as a function of its mass.

c) If we know that the lifetime of our Sun is about 10 billion years, what is the lifetime of a star with a mass $M = 5M_S$?

Question 1	a	b	c	d	e	f
Question 2	a	b	c	d	e	f
Question 3	a	b	c	d	e	f
Question 4	a	b	c	d	e	f
Question 5	a	b	c	d	e	f
Question 6	a	b	c	d	e	f
Question 7	a	b	c	d	e	f
Question 8	a	b	c	d	e	f
Question 9	a	b	c	d	e	f
Question 10	a	b	c	d	e	f
Question 11	a	b	c	d	e	f
Question 12	a	b	c	d	e	f
Question 13	a	b	c	d	e	f
Question 14	a	b	c	d	e	f
Question 15	a	b	c	d	e	f
Question 16	a	b	c	d	e	f
Question 17	a	b	c	d	e	f
Question 18	a	b	c	d	e	f
Question 19	a	b	c	d	e	f
Question 20	a	b	c	d	e	f
Question 21	a	b	c	d	e	f
Question 22	a	b	c	d	e	f
Question 23	a	b	c	d	e	f
Question 24	a	b	c	d	e	f
Question 25	a	b	c	d	e	f