CAP High School Prize Exam

April 8th, 2014

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: _____

Would you prefer further correspondence in French or English? _____

If you are not a Canadian citizen, what is your Immigration Status? _____

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

Sponsored by:

Canadian Association of Physicists,
Canadian Physics Olympiad,

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

Canadian Association of Physicists
2014 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 $R_S = 6.96 \times 10^8\,\mathrm{m}$
Stefan's constant $\sigma = 5.6704 \times 10^{-8}\,\mathrm{W/(m^2 \cdot K^4)}$

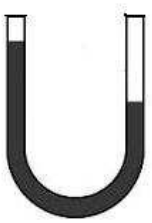
Part A: Multiple Choice

Each multiple choice question is worth 1 point.

Question 1
Consider the electric power dissipation due to resistance in a circuit. Which of the following changes leave the dissipated electric power unchanged?

a) Doubling the voltage and reducing the current by a factor of two.
b) Doubling the voltage and increasing the resistance by a factor of four.
c) Doubling the current and reducing the resistance by a factor of four.
d) None of the above.
e) Both (b) and (c) are correct.
f) (a),(b) and (c) are correct.

Question 2
A U-shaped glass tube closed at both ends and positioned vertically is partly filled with water. At a certain time the levels of water are different in the two arms of the tube due to a difference in air pressure above each arm. If there is no temperature change, what will happen to the water level on both sides?



a) The water levels will stay stationary.
b) The water levels will equalize rapidly — within seconds.
c) The water levels will slowly equalize — within days.
d) The difference between the levels in each arm will increase.

Question 3
How does the magnitude of the gravitational force with which the Moon attracts the Earth compare to the magnitude of the gravitational force with which the Earth attracts the Moon?

a) They are equal.
b) The first is greater.
c) The first is smaller.

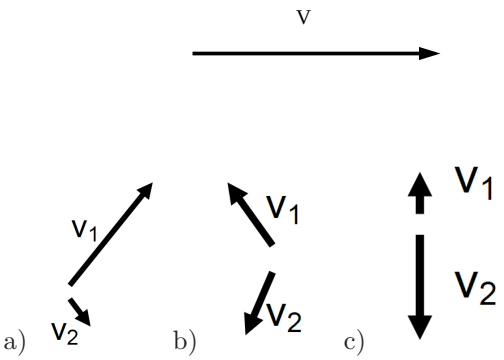
Question 4
The friction force acting on a bicycle is 20 N. What power does a cyclist need in order to travel at 18 km/h?

a) 50 W
b) 100 W
c) 1800 W
d) 3600 W

Question 5
What is the average horizontal force acting on a ball when it elastically bounces off a wall, assuming the collision time is 0.1 s and the momentum of the ball before the bounce was $2\,\mathrm{kg}\cdot\mathrm{m/s}$, perpendicular to the wall?

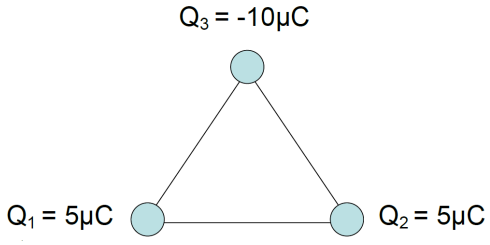
a) 0.2 N
b) 0.4 N
c) 40 N
d) 20 N

Question 6
A small explosion occurs in a model airplane which rips it into two pieces. The model was flying with velocity v just before the explosion. Which combination of v_1 and v_2 are possible velocities of the two pieces after the explosion?



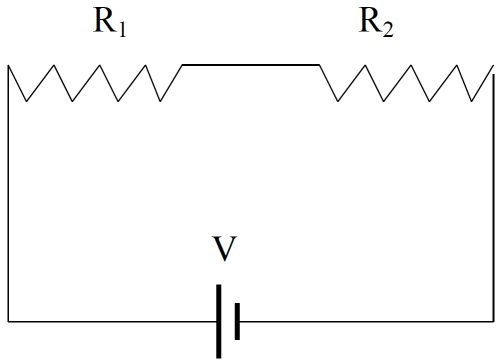
a) b) c)

Question 7
Three ping-pong balls are electrically charged and are arranged in the plane of the page in an equilateral triangle as shown below. What is the direction of the force acting on the ping-pong ball charged with $Q_3 = -10\,\mu\mathrm{C}$?



a) Towards the top of the page.
b) Towards the bottom of the page.
c) Towards the left.
d) Towards the right.
e) Another direction.

Question 8
In the circuit shown below, the resistance R_1 is increased. What happens to the magnitude of the potential difference across R_1?



a) It increases.
b) It decreases.
c) It remains the same.

Question 9
Two identical loudspeakers, placed close to each other, are supplied with the same sinusoidal voltage. One can imagine a pattern around the loudspeakers with alternating areas of increased and decreased sound intensity. Which of the actions below will **not** change the positions of these areas?

a) Moving one of the speakers.
b) Changing the amplitude of the voltage.
c) Changing the frequency.
d) Replacing the air in the room with a gas of a different density.

Question 10
Two artificial satellites, named Argo and Navis, have circular orbits of radii R and $2R$, respectively, about the same planet. The orbital speed of Argo is v. What is the orbital speed of Navis?

a) $v/2$
b) $v/\sqrt{2}$
c) v
d) $v\sqrt{2}$
e) $2v$

Question 11
When someone drags their fingernails across a chalkboard, a terrible high-pitched sound is produced due to small bumps in the chalkboard. Assume these bumps are uniformly spaced by 0.5 mm. Audiologists have determined that humans find sounds in the range of $2 \sim 4\,\mathrm{kHz}$ to be very annoying. An evil teacher wants to produce the longest duration continuous sound in this range by dragging her fingernails across the chalkboard. At what speed should she drag her nails to accomplish this?

a) 0.28 m/s
b) 0.56 m/s
c) 1.00 m/s
d) 2.00 m/s

Question 12
The Hall Effect occurs when both a current and magnetic field are present and perpendicular to each other in a solid. The result is the generation of an electric field and a corresponding potential difference (the Hall voltage) across the width of the solid. Suppose a two-dimensional rectangular material carries a current of 0.5 A in the positive x direction and is penetrated by a magnetic field of 1.4 mT in the negative z direction. The number of mobile charges per unit area of the material is $0.2\,\mu\text{C/m}^2$. What is the magnitude of the Hall voltage, and the direction of the generated electric field? (Assume a right-handed coordinate system)

a) $70\,\mu$V, negative y direction
b) $70\,\mu$V, positive y direction
c) 3.5 kV, negative y direction
d) 3.5 kV, positive y direction

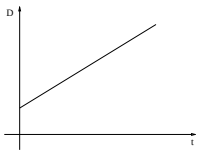
Question 13
^{214}Po atoms have a mass of 3.55×10^{-22} g and decay into ^{210}Pb with a half-life of 160 μs. A detector encompassing 1g of ^{214}Po counts the number of ^{210}Pb daughters produced. An experimentalist rigs an oscillator so that the frequency of electromagnetic radiation it emits matches the frequency of ^{210}Pb counts measured by detector. After 8 ms, what type of electromagnetic radiation is produced by the oscillator?

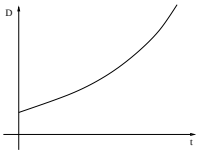
a) Radar
b) Red light
c) Ultra-violet
d) X-rays

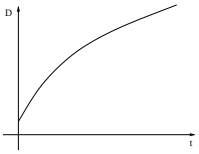
Question 14
To submerge a block of wood which is less dense than water, one needs to exert a force downward which does a positive amount of work on the block. Which of the following is correct for this situation to occur?

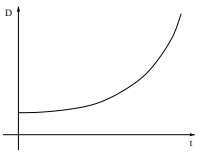
a) The work done by the external force is stored as potential energy in the block.
b) The block is moving downward, therefore its potential energy is decreasing, thus the work done by the external force is all converted to heat, due to friction.
c) The work done by external force is all stored as kinetic energy in the block.
d) The potential energy of the water is increased while the potential energy of the block is decreased.
e) The total energy of the block is conserved.
f) The total energy of the block and water is conserved.

Question 15
In 1929, Edwin Hubble discovered that the universe is expanding. He observed that galaxies far away from us are moving away at a speed that is proportional to their distance from us (you can assume the constant of proportionality is time-independent). For a galaxy that obeys Hubble's law, which of the following can be the graph of distance (from Earth) versus time? For each plot, $t = 0$ corresponds to the present.

a) 

b) 

c) 

d) 

Question 16
Which of the following is closest to the thickness of a piece of paper?

a) 10^{-3} m
b) 10^{-4} m
c) 10^{-5} m
d) 10^{-6} m
e) 10^{-7} m

Question 17
The paper-folding theorem states that in order to fold something in half, it's length must be at least π times its thickness. How many times can you fold a standard sheet of printing paper ($0.216\,\text{m} \times 0.279\,\text{m}$) if you always fold from the middle of the longer edge?

a) 5
b) 6
c) 7
d) 12

Question 18
A circuit contains nothing but a battery of voltage V wired to three resistors of resistance R. Which of the following **cannot** be the power dissipated in the circuit (assuming negligible resistance for the wires)?

a) $P = V^2/(3R)$
b) $P = 3V^2/R$
c) $P = 3V^2/(2R)$
d) $P = 2V^2/(3R)$
e) All of the above are possible

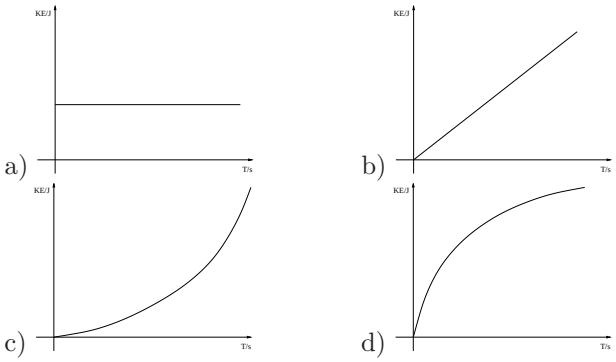
Question 19
In a binary star system consisting of two stars of equal mass, where is the gravitational potential equal to zero? Assume that for a single star in empty space, the potential is zero at infinity.

a) Exactly halfway between the stars.
b) Along a line bisecting the line connecting the stars and perpendicular to the plane of the stars' orbit.
c) Infinitely far from the stars.
d) At any point on a plane bisecting the line connecting the stars and perpendicular to the plane of the stars' orbit.

Question 20
In Young's double-slit experiment, both slits are illuminated by a laser beam and the interference pattern is observed on a screen. If the viewing screen is moving farther from the slits, what will happen to the interference pattern?

a)The pattern gets brighter.
b)The pattern gets brighter and the fringes move closer to each other and to the central fringe.
c)The pattern gets brighter and the fringes move farther from the central fringe and from each other.
d)The pattern gets less bright and fringes appear farther apart.
e)There is no change in the pattern.
f)The pattern becomes unfocused.

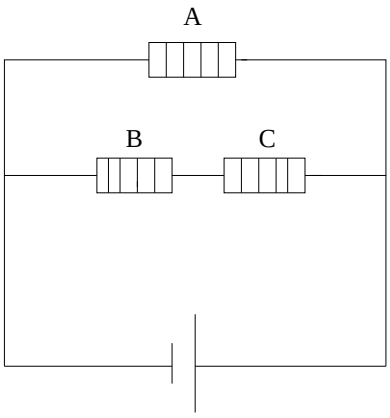
Question 21
A ball is dropped to the Earth from a height of 2 m. Neglecting the air resistance, which one of the following graphs represents the kinetic energy of the ball vs. time?



Question 22
What will happen to the magnitude of the optical power of a lens when it is placed in water ($n = 1.33$) compared to its power in the air ($n = 1$)?

a)It will increase.
b)It will decrease.
c)It will stay the same.
d)It will depend on whether the lens is converging or diverging.

Question 23
The three electric heaters in the following circuit all have the same resistance. Given that the total heat emitted by a heater is proportional to the power dissipated, the total heat produced by B and C together, compared with the heat produced in A, is:



a) A quarter as much.
b) Half as much.
c) The same.
d) Twice as much.
e) Four times as much.

Question 24
A box sits on a horizontal surface that exerts a normal force N on the box. You apply a horizontal force to it and it does not move. If you had applied a force twice as large, it still would not have moved. Let μ_s be the coefficient of static friction of the surface. While you are applying your initial force, which of the following is true of the force of friction acting on the box?

a) $F_f = 0$
b) $F_f < \mu_s N$
c) $F_f \leq \mu_s N$
d) $F_f = \mu_s N$
e) $F_f \geq \mu_s N$
f) $F_f > \mu_s N$

Question 25
Which of the following is closer to the dimensions of a solar cell panel that can produce enough energy for a family in Vancouver in summer time? The following information might be useful:
The price of residential electricity in British Columbia is approximately 6.90 cents per kWh. A typical household's monthly electricity bill is $40 in the summer. The power per area from sunlight that reaches the city of Vancouver is about 0.5 kW/m^2 (averaged over 24 hours) during the period of June-September.
The efficiency of a typical solar cell is about 20%.

a) 30 cm × 30 cm
b) 3 m × 3 m
c) 30 m × 30 m
d) 300 m × 300 m
e) The size of the panel must be much bigger than any of these numbers, since it is always cloudy in Vancouver and the city does not get enough sunshine!

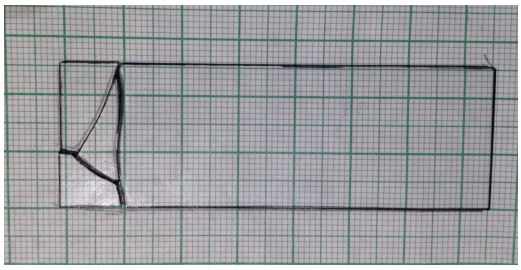
Part B: Problems

Problem 1

When an objects breaks, many of the molecular bonds get detached, but in this process, some of the energy that caused the break turns into heat and sound wave energy.

In this problem we want to understand what percentage of the energy that causes a break is actually used to break the molecular bondings. As a simple model we can think of glass as a cubical structure, which means each SiO_2 molecule occupies a cube of side length a, and each cubic molecule site has 1 bonding with each of its neighbouring cubes. The energy required to break this bond is called bonding energy, denoted by E_b.

Furthermore, in this problem we are only interested in the **order of magnitude** of the values we obtain. The following image shows a piece of glass of dimensions $25\,\text{mm} \times 75\,\text{mm} \times 1\,\text{mm}$ that is fallen down from a height 150 cm and broken into pieces.



a) Using the image, estimate the total length of cracks and thereby the total number of broken bonds.

b) Using the latent heat of vaporization for glass, estimate the bonding energy of glass.

c) What percentage of the energy in this collision is used to break the bonds?

Numerical Values:

- Density of glass: $\rho_g = 2\,\text{g/cm}^3$
- Molecular mass of SiO_2: $M_{SiO_2} = 60\,\text{g/mol}$
- Latent heat of Vaporization for glass: $L_g = 10\,\text{kJ/g}$

Problem 2

The main span of the Lion Gate Bridge has a length of 473 m. On each end there are the expansion joints like the one on the photo below. They allow the span to expand horizontally without warping the steel frame of the span. One day the temperature in Vancouver changed from -4 to $+15$ degrees between 6 in the morning and 2 in the afternoon.

a) What was the average speed of the "tooth" in one of the expansion joints?

b) At 6 in the morning a piece of tire rubber fell into a crack in front of one of the "fingers", filling it completely. The rubber was 10 cm long and had a cross section of $4\,\text{cm}^2$. What was the force acting on the rubber along its length at 2 PM?

c) What will be the vertical force needed to pull this piece of rubber vertically to remove it?

Clearly state all the assumptions that you made while solving this problem. Data: The elastic constant of such a piece of rubber compressed along its length is $28\,\text{N/m}$. The coefficient of friction between the rubber and steel is 0.35. The linear Expansion coefficient of steel $13 \times 10^{-6}\,\text{K}^{-1}$. The linear Expansion coefficient of rubber $77 \times 10^{-6}\,\text{K}^{-1}$.

Problem 3

A planet without atmosphere in orbit around a star radiates away an amount of energy equal to the amount of energy it receives from the star. Therefore, the average surface temperature of the planet is constant over decades. Imagine an Earth-sized planet without atmosphere orbiting around a Sun-sized star (with the same radiation power as the sun) at a distance of 1 AU (AU is the Astronomical Unit, equal to the Earth-Sun distance).

a) What portion of the energy radiated by the star is captured by the planet? (Assume that planet absorbs all the energy it receives)

b) According to Stefan-Boltzmann's law, the power per area emitted from the surface of an object at temperature T is $I = \sigma T^4$ for which σ is Stefan's constant. Assuming the power output of the star is the same as the Sun ($3.85 \times 10^{26}\,\text{W}$), find the surface temperature of the planet. Compare this result to the average surface temperature of the Earth (288 K). How much difference does the atmosphere make in the surface temperature of Earth? Would Earth be warm enough to be habitable for humans if it did not have an atmosphere?

c) Neptune is the outer-most planet in our solar system at distance 30.4 AU. If we assume that Neptune absorbs all the energy it receives from the Sun, what is the average uniform surface temperature of this planet?

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