CAP High School Prize Exam

April 20, 2016

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 you are 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 (CAP),
CAP Foundation,

Canadian Physics Olympiad,

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

Canadian Association of Physicists 2016 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 students who provide full correct solutions 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 $g = 9.81\,\mathrm{m/s^2}$
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 $h = 6.63 \times 10^{-34}\,\mathrm{Js}$
Electrostatic constant $k = 8.99 \times 10^9\,\mathrm{N \cdot m^2/C^2}$
Boltzmann's constant $k_B = 1.38 \times 10^{-23}\,\mathrm{J/K}$
A.U. Astronomical Unit $= 1.49598 \times 10^{11}\,\mathrm{m}$: The approximate distance from the Sun to the Earth.
Radius of the Earth $R_E = 6.371 \times 10^6\,\mathrm{m}$
Mass of the Earth $M_E = 5.972 \times 10^{24}\,\mathrm{kg}$
Radius of the Sun $R_S = 6.96 \times 10^8\,\mathrm{m}$
Mass of the Sun $M_S = 1.989 \times 10^{30}\,\mathrm{kg}$
Stefan's constant $\sigma = 5.6704 \times 10^{-8}\,\mathrm{W/(m^2 \cdot K^4)}$
Avogadro's number $N_A = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$

Part A: Multiple Choice

Each multiple choice question is worth 1 point.

Question 1
A grandfather clock measures time by counting the number of oscillations of a small-angle pendulum. You take a grandfather clock that gives the correct time at sea level (where $g = 9.81\,\mathrm{m/s^2}$) up a mountain and notice that after two days it is running five minutes behind. What is the value of the gravitational acceleration up that mountain?

a) $9.74\,\mathrm{m/s^2}$
b) $9.78\,\mathrm{m/s^2}$
c) $9.84\,\mathrm{m/s^2}$
d) $9.81\,\mathrm{m/s^2}$
e) There is not enough information to answer the question

Question 2
The Hubble space telescope, having a mass of 11 110 kg, is in low-Earth orbit with a semi-major axis of 6 924 km. What is its orbital period?

a) 95.6 minutes
b) 3.02×10^{-3} minutes
c) 2.22×10^{12} minutes
d) 136 minutes
e) 15.2 minutes

Question 3
A 75 kg person gets in an elevator. How much more power must the elevator's motor supply if the elevator is to go up at the same constant speed of 0.5 m/s as it goes up when empty?

a) 221 W
b) 552 W
c) 1470 W
d) 368 W
e) 92.0 W

Question 4
A 2 kg ball is initially stationary on a flat, frictionless surface. It is then hit by a 0.25 kg piece of putty traveling at 25 m/s. After the collision, the putty sticks to the ball. At what speed will the putty-covered ball travel?

a) 8.83 m/s
b) 2.78 m/s
c) 22.2 m/s
d) 3.13 m/s
e) 8.33 m/s

Question 5
You are holding a bottle of pop in your hands on a bus. The bubbles in the pop are going straight up. Suddenly, the bus brakes hard to avoid a road hazard. How is the motion of the bubbles in the pop affected?

a) The bubbles will gain some motion towards the front of the bus.
b) The answer depends on the initial speed of the bus.
c) The motion of the bubbles will not change.
d) The bubbles will gain some motion towards the back of the bus.

Question 6
Consider an open circuit consisting of a battery with voltage V, a resistor of resistance R and a capacitor of capacitance C, all in series. Before closing the circuit, the capacitor carries no charge. After how long does the current running through the circuit drop by half compared to the moment it is closed?

a) RC/V
b) RC $\ln 2$
c) $\frac{1}{\mathrm{RC}}$
d) RC
e) 2 RCV

Question 7
Which value is closest to the average net speed of electrons ("drift speed") in a copper wire of radius 1 mm for a current of 3 Amperes? The density of copper at room temperature is about $9\,\mathrm{g/cm^3}$ and its molar mass is 63.5 g/mol.

a) 6×10^{-5} m/s
b) 2×10^{-3} m/s
c) 3×10^{8} m/s
d) 5×10^{0} m/s
e) 8×10^{4} m/s

Question 8
Consider three charges located at the three vertices of an equilateral triangle of edge length L. Two of the charges have a value of $+Q$ and the third one has a value of $-2Q$. What is the magnitude of the net electric field at the centre of the triangle?

a) 0
b) $4\sqrt{3}kQL^2$
c) $\frac{12kQ}{L^2}$
d) $\frac{9kQ}{L^2}$
e) $\frac{8kQ}{L^2}$

Question 9
An FM radio station broadcasts signals at a frequency of about 100 MHz. What is approximately the wavelength of such a signal?

a) 3m
b) 3×10^6 m
c) 0.3m
d) 0.33×10^{-8} m
e) More information is needed to answer this question

Question 10
A bright flash of light has a measured intensity of $800\,\mathrm{W/m^2}$ at a distance of 1 m from the source. What will be the measured intensity 10 m away from the source, treating the source as point-like?

a) $80\,\mathrm{W/m^2}$
b) $8\,\mathrm{W/m^2}$
c) $800\,\mathrm{W/m^2}$
d) $0.8\,\mathrm{W/m^2}$
e) $8000\,\mathrm{W/m^2}$

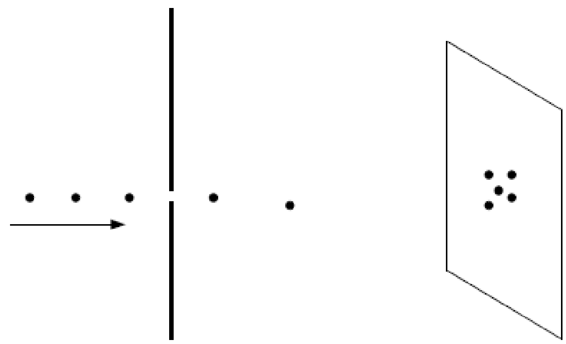
Question 11
Unstable elementary particles are produced traveling at $v = 0.6c$ with respect to an observer in a laboratory. These particles have a typical intrinsic lifetime of 100 ns. In the frame of the observer, how long will the particles typically last before decaying?

a) 125 ns
b) 80 ns
c) 100 ns
d) They won't decay while moving.
e) 175 ns

Question 12
A red beam of light is made up of a stream of photons. If we double the frequency of the beam, keeping the intensity constant, what will happen to the stream?

a) The number of photons will stay the same and the energy of each photon will stay the same.
b) The number of photons will stay the same and the energy of each photon will increase.
c) The number of photons will decrease and the energy of each photon will increase.
d) The number of photons will increase and the energy of each photon will stay the same.
e) The number of photons will increase and the energy of each photon will increase.

Question 13
A beam of electrons is sent through a small hole in a piece of foil. The places where the electrons hit a distant screen are recorded. If we make the hole smaller, the region where the electrons are hitting the screen will be:

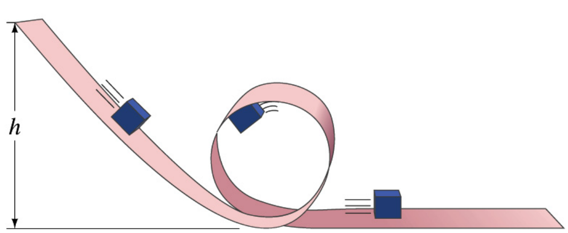


a) bigger
b) the same size
c) smaller
d) there is not enough information to answer.

Question 14
The magnitude of the gravitational force with which a ping pong ball attracts the Earth is:

a) equal to the magnitude of the gravitational force with which the Earth attracts that ping pong ball.
b) greater than the magnitude of the gravitational force with which the Earth attracts that ping pong ball.
c) less than the magnitude of the gravitational force with which the Earth attracts that ping pong ball.
d) zero.
e) unknowable.

Question 15



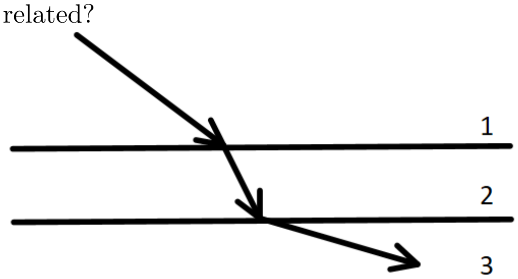
An object is released from rest at a height h. For the object to go around the loop (of radius r) what is the smallest possible value of h?

a) $0.5r$
b) r
c) $2r$
d) $2.5r$
e) $3r$

Question 16
Two projectiles, K and Z, are launched from the top of a building with the same initial speed. Their launch angles (relative to the horizontal ground) are $\theta_K = 45^o$ and $\theta_Z = -45^o$. Which projectile will hit the ground with greater speed (neglecting air resistance)?

a) K
b) Z
c) Both will have the same speed
d) K will never hit the ground
e) There is not enough information to tell

Question 17
A ray of light passes through three media as shown in the figure. How are the speeds of light in these media related?



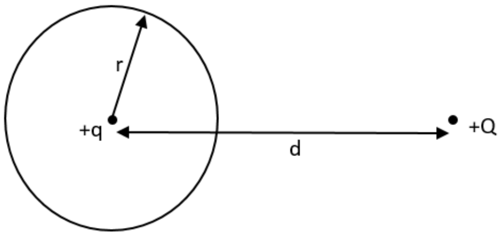
a) $v_3 > v_2 > v_1$
b) $v_1 > v_2 > v_3$
c) $v_2 > v_1 > v_3$
d) $v_3 > v_1 > v_2$
e) $v_1 > v_3 > v_2$

Question 18
Two space heaters are made to output their nominal power of $1000W$ and $500W$ respectively when they are supplied with 120V. If they are connected in series to a normal (120V) wall outlet, compared to only the $1000W$ heater how much heat will be produced?

a) More
b) Less
c) The same amount

Question 19

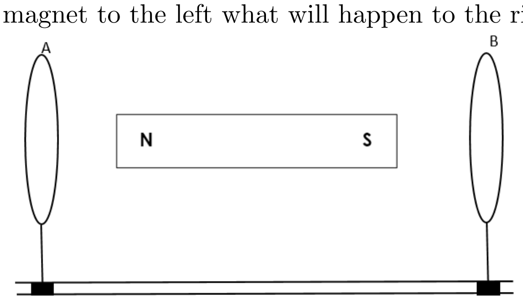
A thin uncharged conducting spherical shell of radius r has a charge q placed in its centre. The charge q does not touch the shell. What is the magnitude of the force acting on a charge Q placed at a distance $d > r$ from the centre of the shell?



a) kqQ/r^2
b) kqQ/d^2
c) 0
d) $kqQ/(r+d)^2$
e) $kqQ/(r-d)^2$

Question 20

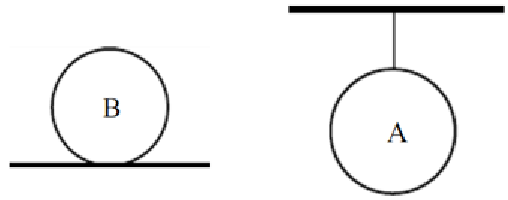
A magnet is held between two conductive rings that are attached to a frictionless rail by two insulators (They can move freely to the left and right). If we move the magnet to the left what will happen to the rings?



a) A will move right and B will move left
b) A will move left and B will move right
c) They will both move left
d) They will both move right

Question 21

Consider two identical homogeneous balls, A and B, with the same initial temperatures. One of them is at rest on a horizontal plane, while the second one hangs on a thread. The same quantity of heat has been supplied to both balls. Which of the following statements is true about the temperatures of A and B?



a) $T_A = T_B$
b) $T_A > T_B$
c) $T_A < T_B$

Question 22

A square hole is cut out from a rectangular sheet of metal. What would the shape of the hole be after heating the piece up? The pictures are focused on the hole and do not show the whole sheet.

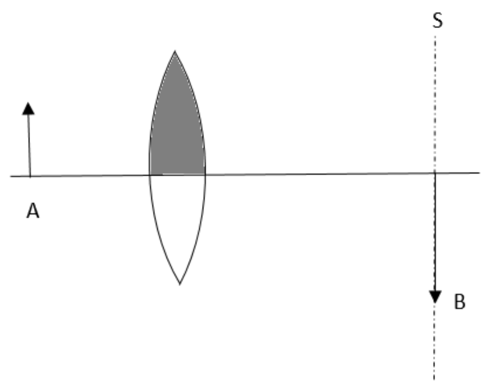
a) 

b) 

c) 

d) 

Question 23
The lens shown below constructs a real image (B) of the arrow (A) on the screen (S). What will happen to the image if we paint the upper half of the lens black?



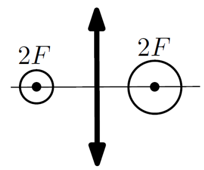
a) The image will get inverted.
b) The upper half of the image will disappear.
c) The lower half of the image will disappear.
d) The shape of the image will remain the same and will only get dimmer.

Question 24
While on a long plane ride over the equator (where the Earth's radius is 6 378 km), the captain announces that the local gravitational acceleration is $9.75\,\mathrm{m/s^2}$. At approximately what altitude is the plane flying?

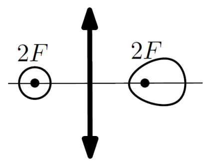
a) 5 500 m
b) 11 000 m
c) 16 000 m
d) 1 100 m
e) 22 000 m

Question 25
A ring is placed at a distance 2F on the left side of a lens of focal distance F, along the optical axis. Which of these pictures best shows the shape of the image?

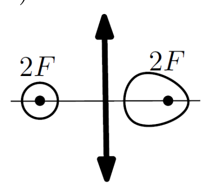
a)



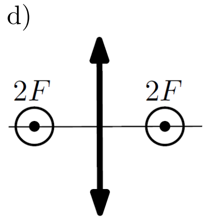
b)



c)



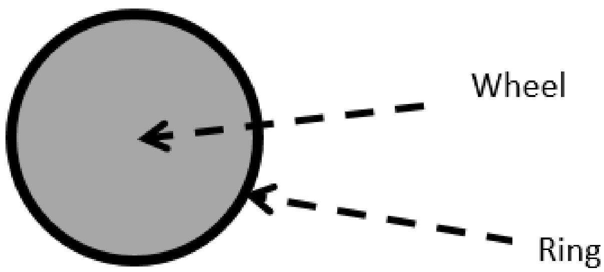
d)



Part B: Problems

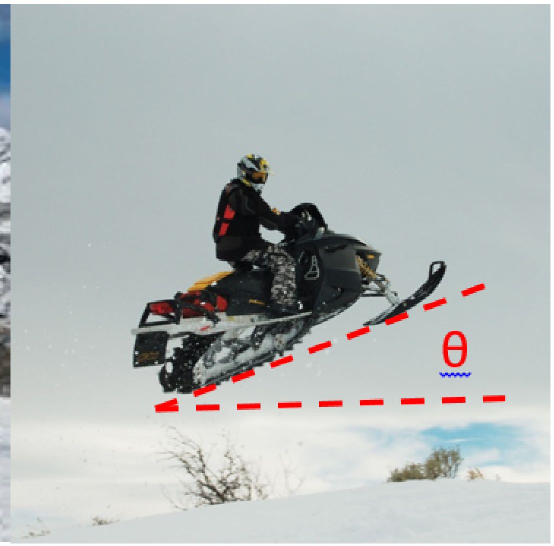
Problem 1

A railway car wheel is made by getting a solid steel wheel of diameter $d = 75\,\text{cm}$ and covering the rim of the wheel with a thin (0.5 cm) ring of hard steel. To do so, the ring is heated to $400\,^oC$. At that temperature it has an inner diameter identical to that of the cold wheel (75 cm). After putting the ring on the wheel, it was cooled back down to room temperature. The coefficient of linear expansion of the steel is $\alpha = 1.2 \times 10^{-5}\,\text{K}^{-1}$ and the elastic constant of a strip of steel with the same cross section and length as the ring is $k = 2.1 \times 10^7\,\text{N/m}$. What force one would need to slide the ring off the wheel (in the direction parallel to the axis)? The coefficient of friction of steel on steel is $\mu = 0.8$.



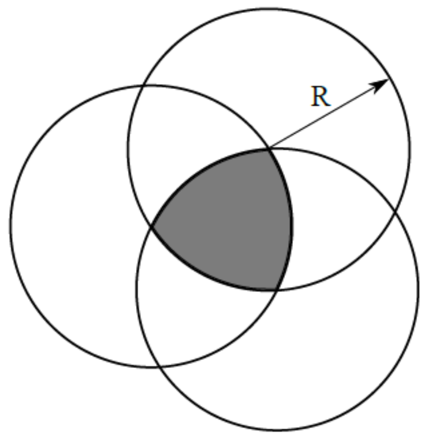
Problem 2

Some people are not satisfied with just driving snowmobiles on snow and try high jumps on them, as seen on these pictures. In flight, the angle θ which the snowmobile makes with the horizontal can be changed by using the brakes or accelerator. Shortly explain how this is done, quoting the appropriate physics laws. Assuming that the mass of the snowmobile with the rider is about 250 kg and the mass of the rotating parts is about 20 kg, calculate what he has to do to tilt the snowmobile by $\theta = 5^o$ down (to lower the front) and then maintain the snowmobile at that angle. State any approximations and size estimates that you make.



Problem 3

A Reuleaux triangle is a two-dimensional figure defined as the intersection of three identical disks placed so that the center of each disk lies on the boundary of the other two (see diagram).



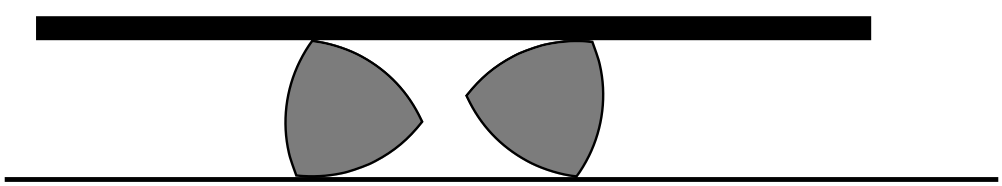
The moment of inertia of a Reuleaux triangle rotating about its centre of mass is given by

$$I = CMR^2 \ ,$$

where M is its mass, R the radius of the circles and C is a numerical constant.

a) Consider a "wheel" in the shape of a Reuleaux triangle with uniform density, resting on a flat surface. What is the frequency of small oscillations of this wheel? Neglect any slipping.

b) Consider two logs with Reuleaux triangle cross-sections placed on a flat horizontal surface and supporting a long flat plank of wood, as shown. Assume no slipping and consider only the time period before one of the logs reaches the end of the plank. Sketch the height of the center of mass of the plank as a function of horizontal displacement.



c) Is there a configuration in part (b) for which the center of mass of the whole system (logs + plank) remains at constant height as the plank moves? Justify your answer.

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	