CAP High School/CEGEP Prize Exam

April 9, 2019

9:00 - 12:00

Student Information Sheet

The following information will be used to inform students 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

Student First Name																									
Student Last Name																									
Teacher Name																									

Address: (Street number and Apt) __________

(City and Province) __________ (Postal Code) __________

Telephone: ( ) __________ Email: __________

School: __________ Grade: __________

Date of Birth: __________

Gender: __________ 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? __________

By signing this page I agree that, if my score on this Exam is in the top 20 nationally or in the top 6 in my province, my name, my school's name, and my ranking can be published.

Student's signature: __________

Sponsored by:

Canadian Association of Physicists;
Canadian Physics Olympiad;
Department of Physics and Astronomy,
University of British Columbia.

2019 Canadian Association of Physicists Highschool/Cegep 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 questions in section A will be used to determine whose written work in section B will be marked for prize consideration by the CAP Exam National Committee. Section A consists of 25 multiple-choice questions. The questions in section B span a range of difficulty, and may require graphing. Be careful to gather as many of the easier marks as possible before venturing into more difficult territory. When you are unable to solve any part of a question, you may assume a likely answer to that part and attempt the rest of the question anyway.

Non-programmable calculators may be used. 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 problems in Section B. Partial marks will be given for partial solutions. There are no penalties for incorrect answers. The questions are not of equal difficulty. Remember that 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 Exam is meant to be tough!

Data

Speed of light $c = 3.00 \times 10^8$ m/s
Gravitational constant $G = 6.67 \times 10^{-11}$ N·m^2/kg^2
Acceleration due to gravity $g = 9.81$ m/s^2
Standard atmospheric pressure $P_0 = 1.01 \times 10^5$Pa
Density of fresh water $\rho = 1.00 \times 10^3$ kg/m^3
Density of ice $\rho_i = 916$ kg/m^3
Specific heat of water $C_w = 4186$ J/(kg·K)
Specific heat of ice $C_i = 2050$ J/(kg·K)
Latent heat of water $L_w = 2260$ kJ/kg
Latent heat of ice $L_i = 334$ kJ/kg
Fundamental charge $e = 1.60 \times 10^{-19}$ C
Mass of an electron $m_e = 9.11 \times 10^{-31}$ kg
Mass of a proton $m_p = 1.67 \times 10^{-27}$ kg
Planck's constant $h = 6.63 \times 10^{-34}$ J·s
Electrostatic constant $k = 1/4\pi\epsilon_0 = 8.99 \times 10^9 N \cdot m^2/C^2$
Permittivity of free space $\epsilon_0 = 8.854 \times 10^{-12}$ C^2/N·m^2
Boltzmann's constant $k_B = 1.38 \times 10^{-23}$ J/K
Stefan–Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ W/m^2· K^4
Astronomical Unit (approximate distance from the Sun to the Earth) 1 AU = 1.49598×10^{11} m
Radius of the Earth $R_E = 6.371 \times 10^6$ m
Radius of the Sun $R_S = 6.96 \times 10^8$ m
Mass of the Earth 5.97×10^{24} kg
Mass of the Sun 1.99×10^{30} kg
H_2 Molar mass 2.016 g/mol
O_2 Molar mass 31.998 g/mol
N_2 Molar mass 28.013 g/mol

Section A

1) Which of the following expressions has the correct units to represent the ground state energy of the electron in a Hydrogen atom? ($\hbar = h/2\pi$ below)

a) $\frac{me^4}{\hbar^2\epsilon_0^2}$

b) $\frac{m}{e^4\hbar\epsilon_0^2}$

c) $\frac{me^4}{\hbar\epsilon_0^2}$

d) $\frac{\hbar^2\epsilon_0^2}{me^4}$

2) A Boeing 747 with mass 400 000 kg, engine thrust (force pushing the plane) of 1000 kN and cross section area of 158 m^2 is circling at constant speed of 500 km/h with the radius of 4 km at constant elevation. The acceleration of the plane and the drag force of the air is:

a) 4.8 m/s^2, 1000 kN

b) 62.5 m/s^2, 1000 kN

c) 4.8 m/s^2, 4 000 kN

d) 62.5 m/s^2, 4000 kN

e) 9.8 m/s^2, 1000 kN

3) The International space station orbits 435 km above the Earth's surface about 15.5 times a day. Every day it covers a distance of about:

a) 42 000 km

b) 660 000 km

c) 21 000 km

d) 330 000 km

e) 620 000 km

4) Two identical cars equipped with rubber bumpers in front and back collide. In the first collision, one of them moves with velocity 4 km/h and hits the other one, which moves in the same direction at 2 km/h. In the second collision they move with the same speeds but with directions opposite to each other. Assume the collisions are elastic and ignore the forces coming from the engine. Assuming that the collisions take the same time, the maximum force on the rubber bumper is:

a) The same in both collisions

b) 2 times bigger in the second one

c) 3 times bigger in the second one

d) 4 times bigger in the second one

e) 9 times bigger in the second one

5) A woman with mass M standing on weight measuring platform repeatedly throws a ball with mass m up in the air and catches it. The ball is up in the air for half of each throw and catch cycle. What is the time averaged weight measured over many periods? Ignore air drag.

a) $(M+m)g$

b) $(M+\frac{m}{2})g$

c) $(M+2m)g$

d) $(M-m)g$

e) Not enough information to find out.

6) A woman riding on a bus suspends a ball of mass m from the ceiling using a massless string while the bus is moving at constant speed on a horizontal road. When the bus is accelerating, with its engine off, down a hill inclined downward with a slope s, what is the change of the angle at which the ball is suspended as observed by the woman on the bus?

a) 0

b) $\tan^{-1}s$ to the front of the bus

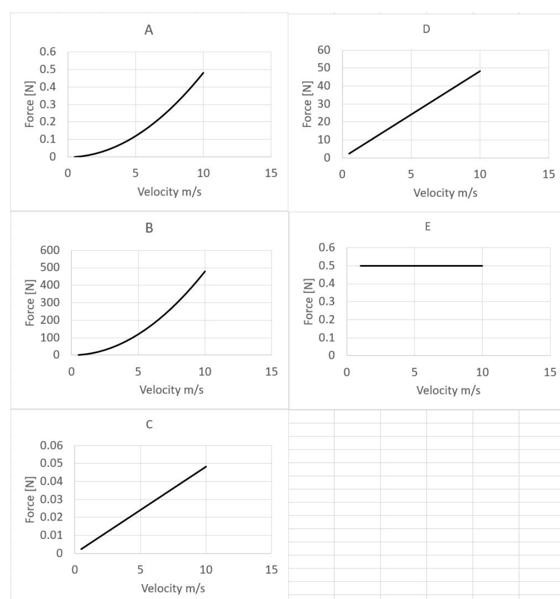
c) $\tan^{-1}s$ to the back of the bus

d) $\sin^{-1}s$ to the front of the bus

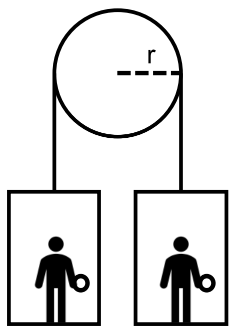
e) $\sin^{-1}s$ to the back of the bus

f) not enough information

7) The drag force (air resistance) of an object moving with velocity v having the cross section A perpendicular to the velocity depends only on A, v, air density ρ and a dimensionless constant C describing the shape of an object. C is close to 0.5 for a sphere. Which graph below best describes the dependence of the drag force on the velocity for the 10 cm diameter ball?



8) Two men of the same mass M are each standing inside a massless box, and the boxes are connected to each other through a massless, frictionless pulley system. Each man is holding a heavy ball of mass m, so that they balance each other, and the system is at rest. When standing on earth, the man on the right can throw the ball vertically upward to a height h above the point at which the ball leaves his hand. To what height, with respect to himself, can he throw the ball when he is standing inside the box? Assume that the ceiling of the box is high enough that the ball can't reach it, and ignore any effect from the mass of the man's hand and arm when is throwing the ball. Assume also that the man on the left remains motionless inside his box.



a) $\frac{M-m}{M+m}h$

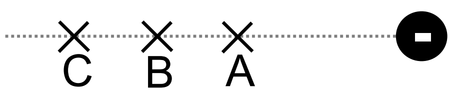
b) $\frac{2M+m}{2(M+m)}h$

c) $\frac{M-m}{2(M+m)}h$

d) $\frac{2M-m}{2(M+m)}h$

e) $\frac{m}{2M+m}h$

9) Three spatial points A, B and C are placed collinearly with an unknown negative charge as shown. Point B is in the middle between A and C. If we set the electric potential at A to be the reference (i.e. potential at A is 0), what are the possible potential at C and B respectively?



	C	B
a)	15V	10V
b)	15 V	5V
c)	20V	10V
d)	-15V	-10V
e)	-15V	-5V
f)	-20V	-10V

10) Two identical metal spheres A and B carry charges $+q$ and $-q$ respectively. They are separated from each other in vacuum space. The force between them is F. Now a third identical sphere C which initially carries a charge $-2q$ touches the sphere A and then the sphere B, after which the sphere C is immediately removed. What is the force between sphere A and B now?

a) F

b) $-F$

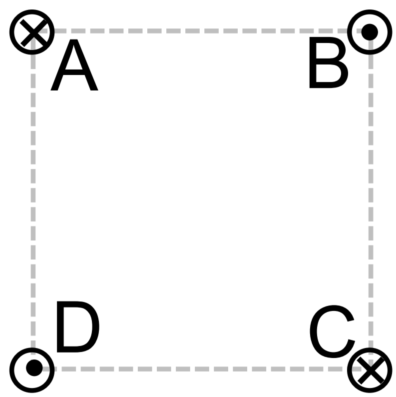
c) $\frac{3}{8}F$

d) $-\frac{3}{8}F$

e) $\frac{1}{4}F$

f) -$\frac{1}{4}F$

11) As in the following figure, four wires are passing through the page at the corners of a square. Wires at A and C both carry current I flowing into the page. Currents at B and D are flowing out of the page. If the net force on the wire at B is zero, what current is flowing out of the page at D?



a) $\frac{I}{\sqrt{2}}$

b) $2I$

c) $\sqrt{2}I$

d) I

e) Not enough information

12) An electron with velocity V enters the uniform Electric field E and uniform Magnetic field B which are perpendicular to each other. The electron's velocity can stay constant if the velocity is:

a) Perpendicular to E and parallel to B and it has magnitude B/E.

b) Perpendicular to B and it has magnitude E/B.

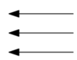
c) Parallel to E and it has magnitude B/E.

d) Perpendicular to E and B and it has magnitude E/B.

13) A proton (charge +e) in an external electric field moves along the path shown below. Which of the following electric fields is the one that gives this path?

a) 

b) 

c) 

d) 

14) A charged particle with mass m and charge q which is affected by the force of gravity and electric force, is moving in a horizontal direction with a steady acceleration g. What is the magnitude of the electric force?

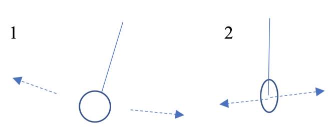
a) 0

b) $\frac{mg}{\sqrt{2}}$

c) mg

d) $mg\sqrt{2}$

15) Two identical coils are suspended from a string and are swinging forth and back as pendula as shown below. Coil 1 swings in the plane of the coil, coil 2 swings in the plane perpendicular to the coil. A current can be induced



a) In both coils as they swing in Earth magnetic field.

b) Only in coil 1

c) Only in coil 2

d) In neither coil

e) It depends on the direction of the Earth field relative to the coils

16) What is the average translational kinetic energy of an air molecule at room temperature (i.e. 25°C)?

a) 1.726 x 10^{-22} J

b) 2.057 x 10^{-21} J

c) 5.177 x 10^{-22} J

d) 6.171 x 10^{-21} J

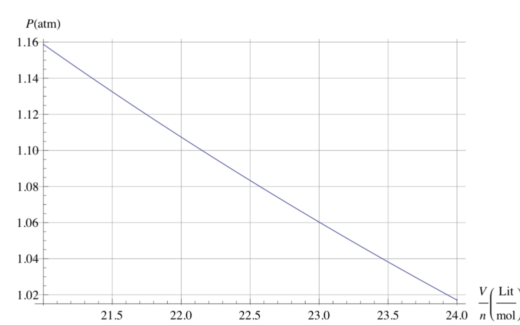
e) Not enough information

17) The equation of state for some gases can be approximately expressed in the following way:

$$(P + a\frac{n^2}{V^2})V = nRT$$

where P is pressure
V is volume
n is the number of moles of a substance,
V/n is molar volume, the volume of 1 mole of gas
T is temperature
$R \approx 8.3144621$ J/mol·K is the gas constant
a is substance-specific van der Waals constant, in units of $\frac{kPa\ell^2}{mol^2}$, where ℓ means litres.

The following diagram shows the pressure of carbon disulphide gas in terms of volume per mole at temperature of 300 K. What is the van der Waals constant for this gas?



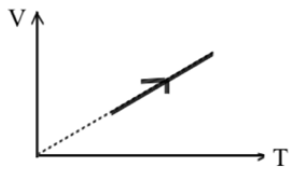
a) 1300

b) 2000

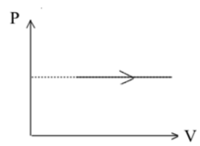
c) 850

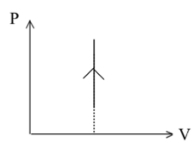
d) 1150

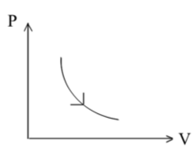
18) A system can be described by three thermodynamic variables: pressure, volume, and temperature. In an ideal gas system, the volume-temperature graph is as below:

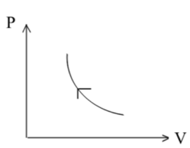


Which one of the following diagrams is Pressure-Volume graph corresponding to this process?

a) 

b) 

c) 

d) 

19) A Carnot cycle operates using a heat reservoir at a temperature T_H and a cold reservoir at temperature T_C. How will the operation efficiency change if we decrease T_H and T_C by the same amount?

a) It increases.

b) It decreases.

c) It doesn't change.

d) It depends on how much we change T_H and T_C.

20) Two soap bubbles combine, forming a bigger one. After the temperature stabilizes to become the same ambient temperature as before, is the volume of the gas inside the bigger bubble:

a) The same as the sum of the volumes of the smaller bubbles

b) Larger than the sum of the volumes of the smaller bubbles

c) Smaller than the sum of the volumes of the smaller bubbles

d) Not enough information to find out.

21) A mercury thermometer was just put into a glass of water. If the thermometer reads 20°C, we can be certain that:

a) The temperature of the water is 20°C.

b) The temperature of the mercury in the thermometer is 20°C.

c) Both A and B

d) Neither A nor B

22) Alice and Bob are travelling at two different constant velocities. In Alice's frame of reference, two explosions occur 1 second apart in time and 2 light seconds apart in space. If these two explosions occur time t apart and distance x apart in Bob's frame of reference, which statement is necessarily correct?

a) $(ct)^2 > x^2$

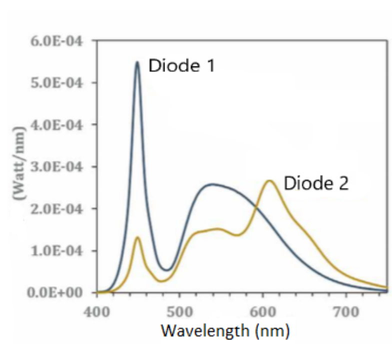
b) $(ct)^2 = x^2$

c) it is possible that $t = 0$

d) it is possible that $x = 0$

e) more than one of the options above is correct

23) The following graphs show the energy emitted by two LED's as a function of wavelength. These are both 0.2 W LED's (they take 0.2 W of electricity when connected). Which one is the most efficient visible light source and what is approximately its efficiency.



a) Diode 1, 50%

b) Diode 2, 40%

c) Diode 1, 25%

d) Diode 2, 20%

e) Both have the same efficiency, 50%

24) A man is walking at speed v_m in front of an ambulance travelling towards him at speed v_a . The siren on the ambulance is emitting a sound at speed c. Since the ambulance is moving faster than the man (i.e. $v_m < v_a$), it overtakes the man later. What is the ratio of wavelength of the sound perceived by the man when the ambulance is approaching him to that when it is leaving him?

a) $\frac{v_a+v_m}{v_a-v_m}$

b) $\frac{c+v_a}{c-v_a}$

c) $\frac{c-v_a}{c+v_a}$

d) $\frac{c+v_m-v_a}{c-v_m+v_a}$

e) $\frac{c-v_m+v_a}{c+v_m-v_a}$

25) Compare the photon emitted when an electron drops from the n=2 to the n=1 state to the photon emitted when an electron drops from n=3 to n=2. Which photon has the longer wavelength? Electron's ground state energy is -13.6 eV. (1 eV = 1.602×10^{-19} J)

a) The photon emitted in the n=2 to n=1 transition

b) The photon emitted in the n=3 to n=2 transition

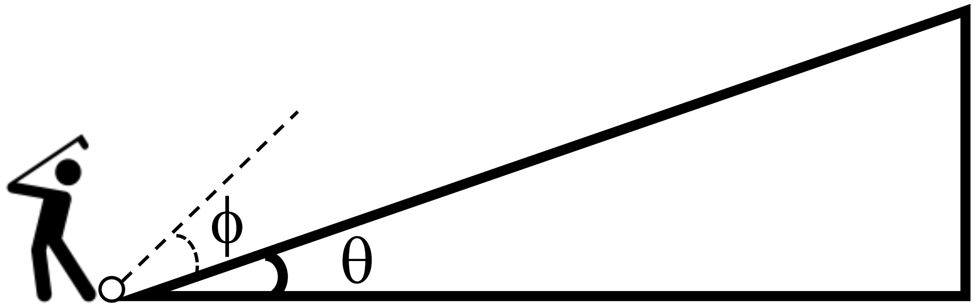
c) Both have same wavelength

d) Not enough information given

End of Section A

Section B starts on next page

1)



A golfer is playing golf facing an inclined plane of inclination angle θ as shown in the figure. When he strikes the ball, the ball flies towards the inclined plane. The ball left the ground at an angle ϕ relative to the inclined plane. What is the value of ϕ at which the ball can land the farthest distance along the incline? Neglect air resistance and assume the inclined plane is infinitely long.

2) A water bottle with diameter of 6.5 cm, made of transparent material, is left lying sideways on the wooden floor on the terrace, which is fully exposed to the sun during the whole day.

1. Show that it can start a fire on the wood floor.
2. How far away from the line along which the bottle touches floor will the fire start?
3. What will be the angular position of the sun above the horizon?

State clearly all the assumptions and approximations you made.

The solar constant s (the amount of solar radiation energy hitting the square meter surface) at the Earth surface is about 1 kW/m^2. Ignition temperature of wood is about 500 °C.

The object at the temperature T emits the energy $P = eA\sigma(T^4 - T_0^4)$ where T_0 is the surrounding temperature, σ is the Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8} W/m^2K$ and A is the emitting surface. Assume emissivity of wood $e = 1$. Ignore the heat conductivity of wood.

You might find the following lens equations (which also approximately apply to the thick and cylindrical lenses) useful:

$$\frac{1}{d_i} + \frac{1}{d_0} = \frac{1}{f}$$

where d_0 is distance from lens to object, d_i is the distance from lens to image, and f is the focal length of the lens.

$$M = \frac{h_i}{h_0} = \frac{d_i}{d_0}$$

where h_i and h_0 are the sizes of the image and object. M is the magnification, which is the ratio of image size to object size.

The lens made of material with index of refraction n with the surfaces of the radii R_1 and R_2 has a focal length f.

$$\tfrac{1}{f} = (n-1)(\tfrac{1}{R_1} - \tfrac{1}{R_2})$$

The h/d ratio for the sun is about 1/110. Index of refraction of water n=1.33

3) A proton (mass $m_p = 938$ MeV/c^2) can be turned into a new particle called delta (Δ^+, mass $m_\Delta = 1232$ MeV/c^2 when it absorbes a photon (denoted with γ, massless):

$$p^+ \; + \; \gamma \; \rightarrow \; \Delta^+ \; .$$

In such relativistic process, energy and momentum are necessarily conserved. The total relativistic energy of a particle depends on its momentum p and mass m through

$$E^2 = (pc)^2 + (mc^2)^2 \; ,$$

where c is the speed of light. For a massless particle, this simplifies to

$$E = |p|c \; .$$

Consider an ultra-relativistic proton, whose speed is close to the speed of light and whose momentum is much larger than $m_p c$ absorbing a very low energy (long wavelength) photon in a head-on collision.

(a) Determine the total relativistic energy of the proton E_p in terms of the (small) energy of the photon E_γ. Clearly state and justify all approximations made.

(b) If the absorbed photon has wavelength 1.063 mm, what must be the energy of the proton so that it is possible to produde a delta particle in such a head-on collision?

(c) If this photon were to collide with the proton at a different angle, would your answer to part (b) be larger or smaller?

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