CAP High School Prize Exam

April 14th, 2015

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
2015 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

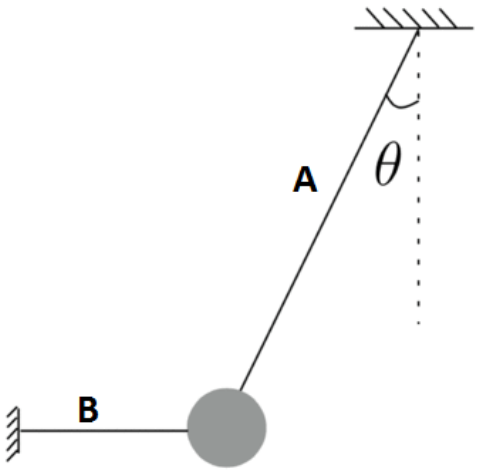
Speed of light $c = 3.00 \times 10^8\,\mathrm{m/s}$
Gravitational constant $G = 6.67 \times 10^{-11}\,\mathrm{N \cdot m^2/kg^2}$
Acceleration due to gravity $g = 9.80\,\mathrm{m/s^2}$
Normal atmospheric pressure $P_0 = 1.01 \times 10^5\,\mathrm{Pa}$
Density of fresh water $\rho = 1.00 \times 10^3\,\mathrm{kg/m^3}$
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 $\sigma = 5.6704 \times 10^{-8}\,\mathrm{W/(m^2 \cdot K^4)}$
H_2 Molar mass $2.016 g/mol$
O_2 Molar mass $31.998 g/mol$
N_2 Molar mass $28.013 g/mol$

Part A: Multiple Choice

Each multiple choice question is worth 1 point.

Question 1

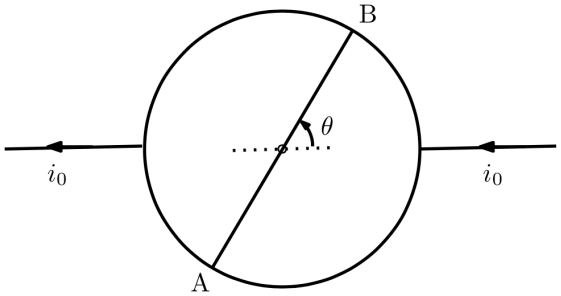
As shown in the picture, a ball is attached to a ceiling and a wall with massless ropes A and B. Rope A is at angle θ from the vertical direction, and rope B is horizontal. The system is static. If rope B is cut, what is the ratio of the tension in rope A immediately after it is cut to the tension in A before it is cut?



a) 1
b) $\cos\theta$
c) $1/\cos\theta$
d) $\cos^2\theta$
e) $\cos\theta \sin\theta$

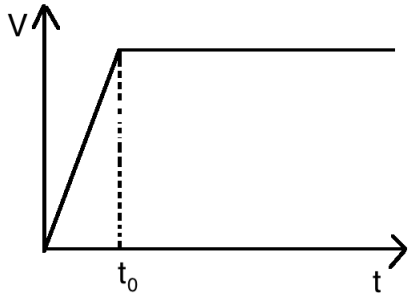
Question 2

Consider a circuit made of a wire with uniform resistance in a shape of a circle as shown in the picture. The circle is connected diagonally from point A to point B with the same type of wire. If the current passing through the circuit is i_0, what is the current passing through the wire AB as a function of angle θ?

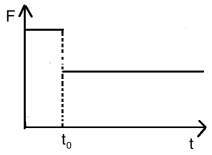


a) 0
b) $\frac{\theta}{\pi-\theta} i_0$
c) $\frac{\pi-2\theta}{\pi+2} i_0$
d) $\frac{\pi-2\theta}{\pi+4} i_0$

Question 3
The following graph represents the speed of a car as a function of time. We know that as the car speeds up there is a friction force with air that can be approximately considered to be proportional to the speed of the car.



Which of the following graphs can be the force of the engine as a function of time?

a)


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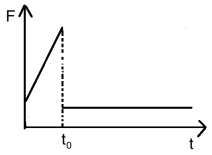
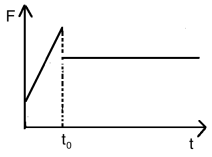
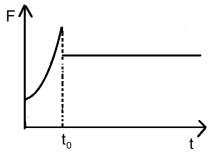
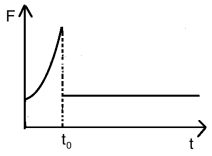


c)


d)


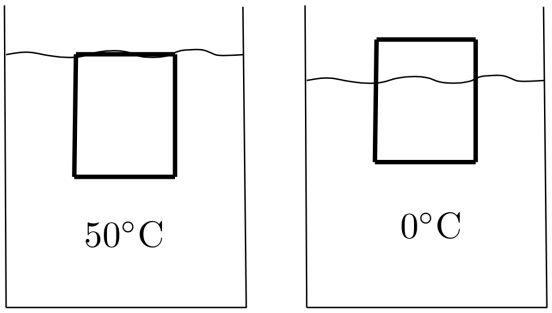
e)


Question 4
If electromagnetic radiation with intensity I (power per unit area) is absorbed by a surface, it exerts a pressure on the surface that is given by $\frac{I}{c}\cos\theta$, where c is the speed of light and θ is the angle the light rays hit the surface relative to a direction perpendicular to the surface. The Sun has a radiation power of $P = 3.9\times10^{26}$ W. The absorption of sunlight by Earth causes a force on Earth that pushes it away from the Sun. Which of the following is closest to the magnitude of this force?

a) 10^7 N
b) 10^9 N
c) 10^{11} N
d) 10^{13} N

Question 5
As shown in the picture a cylinder with volumetric thermal expansion coefficient of $\beta_c = 3\times10^{-6}/\,^oC$ is completely submerged and floating in a fluid at the temperature 50^oC. The fluid has volumetric thermal expansion coefficient of $\beta_f = 8\times10^{-5}/\,^oC$. If we cool down the cylinder and the fluid to 0^oC what percentage of the cylinder's height will be out of the fluid?

a) 0.39 %
b) 0.42 %
c) 0.78 %
d) 0.84 %



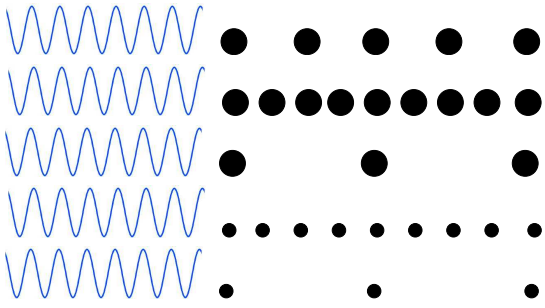
Question 6
The amount of sunlight absorbed by the Earth's atmosphere is approximately proportional to the length of air through which it travels to reach to the Earth. Which of the following is closest to the ratio of the absorption of sunlight during sunset relative to the absorption when the Sun is exactly at the center of the sky? The effective height of the atmosphere is about 10 km.

a) 22
b) 36
c) 45
d) 64

Question 7
A beam of red light is made up of a stream of photons. The size of dots represents the photon energy, and the spacing represents the spatial distribution between photons.:

If we use photons of half the wavelength of red light, keeping the intensity constant, what should the stream look like?

a)
b)
c)
d)
e)



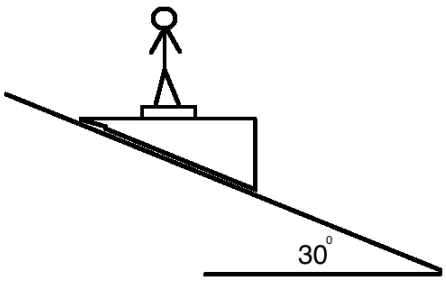
Question 8

To paint the surface of a solid metal sculpture we need 100 buckets of paint. If we melt the sculpture and create 1000 smaller but otherwise identical sculptures, how many buckets of paint are needed to paint the surface of all 1000 small sculptures? Assume that the original and the smaller sculptures are all solid with no cavity inside.

a) 10
b) 100
c) 1000
d) 10000

Question 9

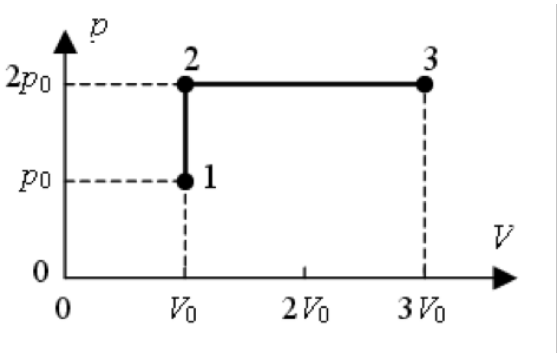
A person is standing on a platform that is sliding down the hill as shown in the picture. The slope of the hill is 30^o with respect to the horizontal. The person is standing on a scale positioned on the surface of the platform and the scale is reading only 150 lbs while his real weight is 160 lbs. Which of the following is the coefficient of kinetic friction between the platform and the slope?



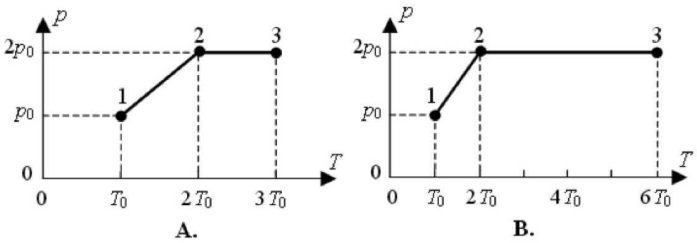
a) $\frac{\sqrt{3}}{2}$
b) $\frac{\sqrt{3}}{4}$
c) $\frac{\sqrt{3}}{3}$
d) $\frac{\sqrt{2}}{3}$
e) there is not enough information to calculate the friction coefficient.

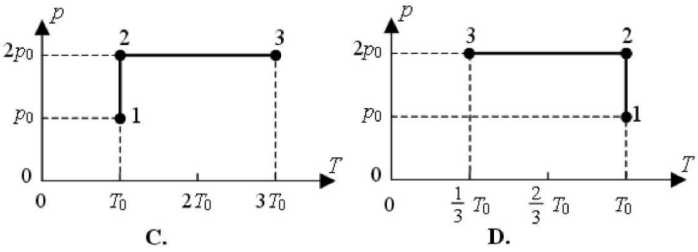
Question 10

A constant amount of ideal gas, at the temperature T_0, undergoes a process that changes its pressure from P_0 to $2P_0$. Then its volume is increased from V_0 to $3V_0$ at a constant pressure, as shown on PV diagram:



Which of the PT diagrams below correctly reflects these processes:





Question 11

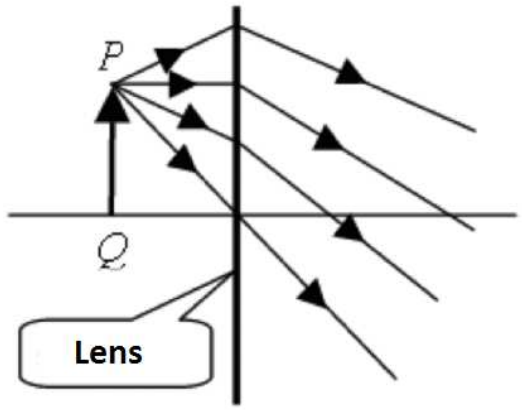
A sentence from a book by a famous bestselling author Dan Brown:

The pilot nodded. "Altitude sickness. We were at sixty thousand feet. You're thirty percent lighter up there. Lucky we only did a puddle jump. If we'd gone to Tokyo I'd have taken her all the way up a hundred miles. Now that'll get your insides rolling."

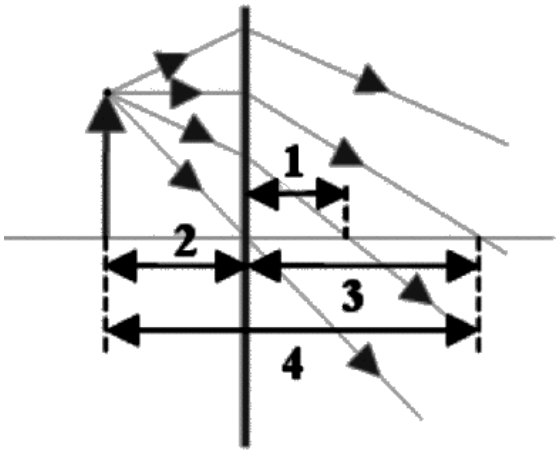
Is the statement correct?

a) Yes
b) No, the distance from the surface of the Earth have to be about 1000 km for a person to feel 30% lighter.
c) No, the person will not feel lighter at higher altitude since the upward force of airplanes engine compensates for the lack of gravity
d) No both arguments 2 and 3 are true

Question 12



The figure above shows some light rays coming from point P and passing through a lens.
Which of the distances shown in the diagram below corresponds to the focal length of this lens?



a) 1
b) 2
c) 3
d) 4

Question 13
A passenger of a train that is moving with the speed of 25 m/s sees from his seat far from a window that it takes 6 seconds for another train to pass the window completely. If the length of the second train is 300 m and it is going in the opposite direction, what is its velocity?

a) 15 m/s
b) 20 m/s
c) 25 m/s
d) 30 m/s
e) 35 m/s

Question 14
An observer is running toward a mirror with a speed of 15 km/h, and the mirror is moving toward the observer with a speed of 10 km/h. What is the relative speed with which the observer sees his image approaching him?

a) 10 km/h
b) 20 km/h
c) 25 km/h
d) 30 km/h
e) 50 km/h

Question 15
Three identical closed containers are filled with gases at the same temperature. Container A is filled with 64 g of oxygen, container B is filled with 84 g of nitrogen, and container C is filled with 8 g of hydrogen. Which is the correct ranking of the pressures in the containers?

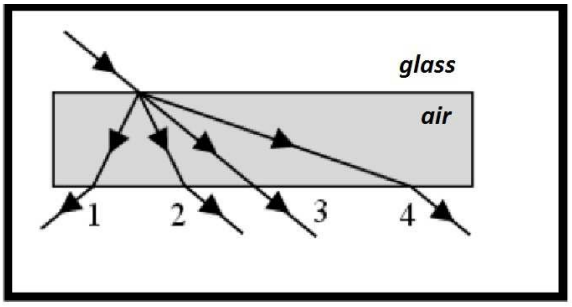
a) $P_A > P_B > P_C$
b) $P_A > P_C > P_B$
c) $P_A < P_C < P_B$
d) $P_A < P_B < P_C$
e) $P_A = P_B > P_C$

Question 16
A ball is placed on a massless spring that is held at an angle of θ with respect to the horizontal. The spring is then compressed a distance of x and released. When the ball reaches the maximum height of its trajectory, it is traveling at a speed v. Then a different ball, weighing four times as much as the first, is placed on the spring which is still at an angle θ. The spring is again compressed a distance x and released. Compared to the first ball, the second ball reaches a maximum height that is

a) $\sin^2\theta$ times as high.
b) 1/4 times as high.
c) $\frac{v^2 g}{x}$ times as high.
d) 4 times higher.

Question 17

A laser beam propagating in glass (shown in white) hits the rectangular gap filled with air (shown in gray). Which line shown on the figure below represents correct path of the beam?



a) 1
b) 2
c) 3
d) 4

Question 18
A parallel beam of light of frequency 6.9×10^{14} Hz enters a glass plate with an index of refraction $n = 1.5$. The frequency of light in the glass is:

a) 4.6×10^{14} Hz
b) 6.9×10^{14} Hz
c) 10.36×10^{14} Hz
d) 13.8×10^{14} Hz

Question 19
Students are watching a science fiction movie where the blood spilled during a battle on the a spaceship with its engines turned off form spheres floating in air. The students think it is unphysical.

a) The students are right, because the blood should not form spheres.
b) The students are wrong, because in free fall the liquid should form into spheres due to atmospheric pressure.
c) The students are wrong, because in free fall the liquid should form the spheres due to the surface tension.
d) The students are right, because the gravitational forces should immediately pull the blood toward the walls or other objects on the ship.

Question 20
Unstable elementary particles are produced traveling at $v = 0.6$c with respect to an observer in a laboratory. These particles have a typical intrinsic lifetime of 100ns. In the frame of the observer, how long will the particles typically last before decaying?

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

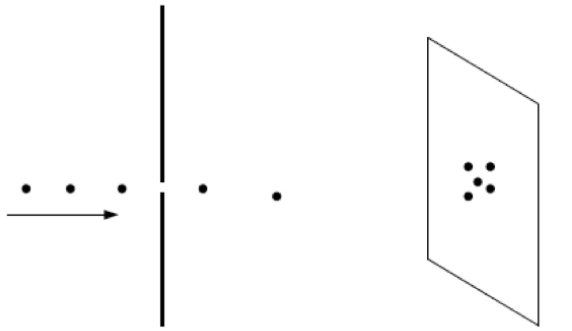
Question 21
A charged moving object enters a volume where a uniform field is present. After some time the object moves in a circular orbit. Which field was present in this area?

a) gravitational
b) magnetic
c) electrostatic
d) both a or c are possible
e) both b or c are possible

Question 22
Students are watching a science fiction movie where the crew of one spaceship watches an explosion on the other spaceship. After a short time interval the crew hear the sound of the explosion. The students think it is unphysical.

a) The students are right, because there should be no delay: the sound propagates in vacuum at the speed of light.
b) The students are wrong. The science advisor of the movie made it according to the laws of physics.
c) The students are right, because the steel body of the spaceship blocks the sound
d) The students are right, because sound cannot propagate in the region between the spaceships

Question 23
A beam of electrons is sent through a small hole in a piece of foil. The places where the electrons hit on 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
c) smaller

Question 24
An astronaut takes a pendulum up to the International Space Station (ISS). The ISS orbits 330 km above the surface of the Earth. The radius of the Earth is 6371 km. Compared to when it is at ground level, the pendulum on the ISS swings with a period that is:

a) 49.3×10^{-3} times as long.
b) 0.95 times as long.
c) 1.05 times longer.
d) 20.3 times longer.
e) The pendulum does not swing on the ISS.

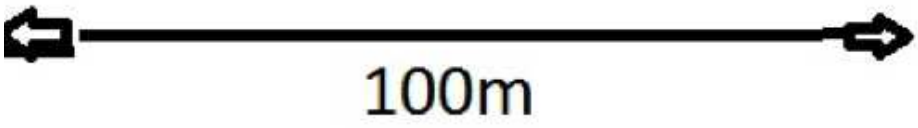
Question 25
Two objects, A and B, appear to be the same length in a reference frame when A is stationary and B is moving with speed $\frac{3}{5}$c along its length. In the frame of reference where B is stationary and A is moving, what is the ratio of their lengths?

a) $\frac{L_A}{L_B} = \frac{5}{4}$
b) $\frac{L_A}{L_B} = \frac{16}{25}$
c) $\frac{L_A}{L_B} = \frac{4}{5}$
d) $\frac{L_A}{L_B} = \frac{9}{25}$
e) $\frac{L_A}{L_B} = \frac{25}{16}$

Part B: Problems

Problem 1

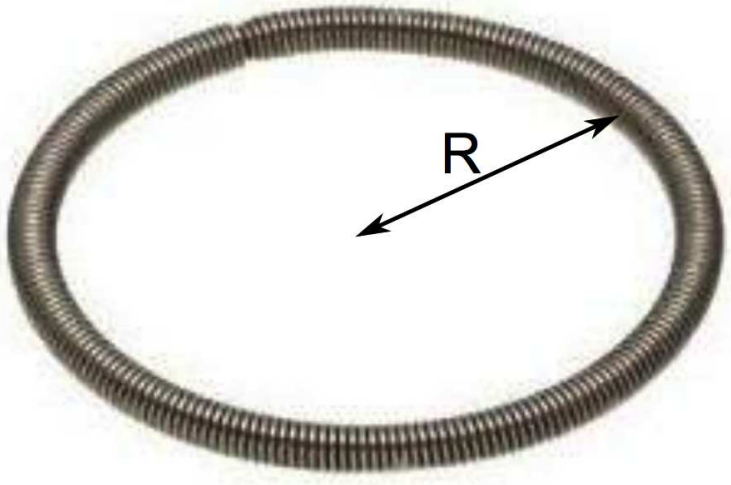
The picture below shows a gravel shooter, a fast moving conveyor belt that shoots the gravel to the desired point on the construction site. Perform some measurements on the photograph and calculate the speed with which the gravel leaves the end of the conveyor belt.



a) Estimate the uncertainty of your answer.
b) Estimate how much the air drag (friction) affects the distance to which gravel is shot.
c) What is the average drag force on the gravel?

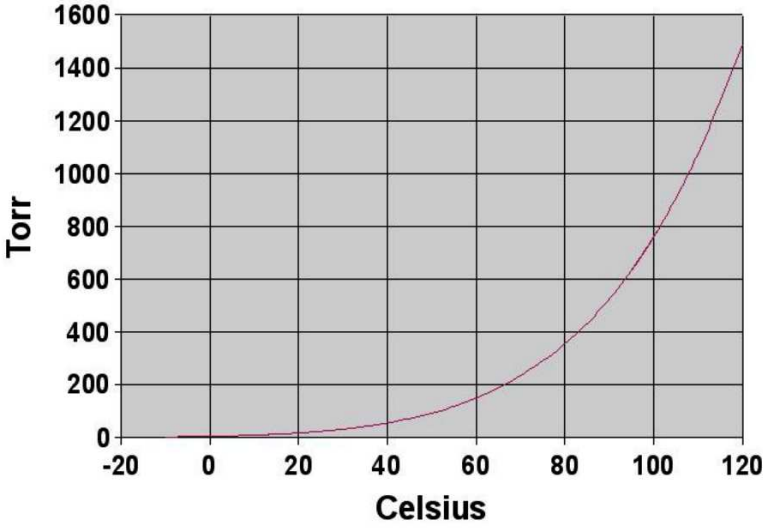
Problem 2

An astronaut on a spacewalk loses her grip on a circular garter spring (pictured below). Looking at the spring she notices that it is rotating around its axis of rotational symmetry at a rate of 300 rpm. The circumference of the rotating garter spring is 1% longer than that of the garter spring when at rest. Calculate the spring constant of the spring if the radius of the rotating garter spring is R = 20 cm and its mass is 1 kg. (We are looking for the spring constant of the spring if it were cut open and stretched along a straight line.)



Problem 3

The vapor pressure is the pressure at which a liquid can be in equilibrium with its own vapor. When the pressure in the liquid is lower than the vapor pressure, the liquid begins to boil. The vapor pressure increases with temperature. The following pictures represents the vapor pressure of water, in Torr (760 Torr = 1 atm), as a function of temperature in Celsius.



Imagine a tall column of water on the Moon, maintained at a temperature of 50°C and left open to the vacuum at the top. Up to what depth will the water in this column boil? The Moon's radius is 0.273 that of the Earth's and its mass 1.23% that of the Earth'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


0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20