CAP High School Prize Exam

April 11, 2017

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																									

Home Address: _____

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 the Canadian Association of Physicists prize exam be in the top 20 nationally or the top 6 in my province I agree that my name, school name, and ranking will be published.

Students signature: _____

Sponsored by:

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

Canadian Association of Physicists 2017 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 25 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 $c = 3.00 \times 10^8 m/s$
Gravitational constant $G = 6.67 \times 10^{-11} N \cdot m^2 kg^2$
Acceleration due to gravity $g = 9.81 m/s^2$
Normal atmospheric pressure $P_0 = 1.01 \times 10^5 Pa$
Density of fresh water $\rho = 1.00 \times 10^3 kg/m^3$
Specific heat of water $C_w = 4186 J/(kg \cdot K)$
Specific heat of ice $C_i = 2050 J/(kg \cdot K)$
Latent heat of water $L_w = 2260 kJ/kg$
Latent heat of ice $L_i = 334 kJ/kg$
Density of ice $\rho_i = 916 kg/m^3$
Fundamental charge $e = 1.60 \times 10^{-19} C$
Mass of electron $m_e = 9.11 \times 10^{-31} kg$
Mass of proton $m_p = 1.67 \times 10^{-27} kg$
Planck's constant $h = 6.63 \times 10^{-34} Js$
Electrostatic constant $k = 8.99 \times 10^9 N \cdot m^2/C^2$
Boltzmann's constant $k_B = 1.38 \times 10^{-23} J/K$
A.U. Astronomical Unit $= 1.49598 \times 10^{11} m$: The approximate distance from the Sun to the Earth.
Radius of the Earth $R_E = 6.371 \times 10^6 m$
Radius of the Sun $R_S = 6.96 \times 10^8 m$
Stefan's constant $\sigma = 5.6704 \times 10^{-8} W/(m^2 \cdot K^4)$
H_2 Molar mass $2.016 g/mol$
O_2 Molar mass $31.998 g/mol$
N_2 Molar mass $28.013 g/mol$
Mass of the Earth 5.97×10^{24}kg
Mass of the Sun 1.99×10^{30}kg

1) On a dry day you comb your hair. Afterwards you notice that bringing the comb close to small bits of paper attracts the paper, causing it to jump off the table towards the comb. The correct explanation for this phenomena involves:

a) The comb is positively charged after combing, and the paper is negatively charged.

b) The comb is negatively charged after combing, and the paper is positively charged.

c) The comb is charged and the paper has no net charge.

d) The comb has no net charge and the paper has no net charge.

e) The comb has no net charge, the paper has positive charge.

2) It takes a ray of light roughly 2.5 million years to travel from our galaxy to the Andromeda galaxy. In a new science fiction film, travelers aboard a spaceship reach the Andromeda galaxy by traveling at high speed. The travelers get about 15 years older during the journey. Which of the following statements is true?

a) This is impossible, although an observer on Earth would see the travelers aging slowly, in fact the observers age more quickly.

b) This is impossible, the travelers would need to live for at least 2.5 million years to reach the Andromeda galaxy.

c) This is a possible scenario. An observer in the Andromeda galaxy would measure the travel time to be over 2.5 million years, but time runs more slowly for the travelers.

d) This is a possible scenario, but only if the travelers go faster than the speed of light.

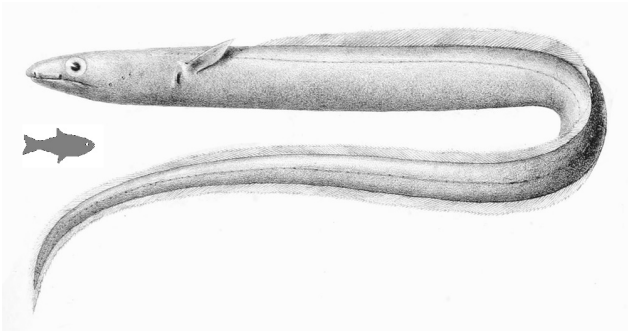


Figure 1

3) *Electrophorus electricus*, commonly known as the electric eel, is capable of producing an 860 volt difference between its head and tail. When using this ability to stun prey, the electric eel will sometimes form a U shape as shown in Fig. 1. This has the effect that the eel's prey is more likely to be stunned. Why is this?

a) The voltage difference between head and tail is increased.

b) The electric field between the head and tail is increased.

c) The electric field near the center of the eel is increased.

d) The voltage at the head and tail are increased by the same amount.

4) The creatures of flatland inhabit a 2-dimensional world. Square, a man of good standing in flatland, holds a hot candle which emits light of intensity 36 Watts. 3 metres away, a detector feels:

a) $\frac{6}{\pi}$ W/m

b) $\frac{1}{\pi}$ W/m^2

c) $\frac{6}{\pi}$ W/m^2

d) $\frac{1}{\pi}$ W/m

e) $\frac{6}{\pi}$ W

5) A tennis ball rolls along a rough surface. Initially the ball has a speed v. After a distance d the speed has been reduced to $v/2$. What total distance will the tennis ball travel? Assume that the rough surface applies a constant force to the tennis ball.

a) $2d$

b) $3d$

c) $\frac{7d}{3}$

d) $d + \frac{d}{2}$

e) $\frac{4d}{3}$

6) You hold your arms outstretched and level in front of you. You rest a meter stick on your hands, with the 0 cm mark on your left hand and the 75 cm mark on your right hand. Slowly and keeping your hands level, you bring your hands together. When your hands touch each other, they will be at the mark for

a) 0 cm

b) 25 cm

c) 37.5 cm

d) 50 cm

e) 75 cm

7) If a stationary object was released near to the surface of the Sun, with approximately what acceleration would it fall?

a) 5 m/s^2

b) 10 m/s^2

c) 20 m/s^2

d) 250 m/s^2

e) 1000 m/s^2

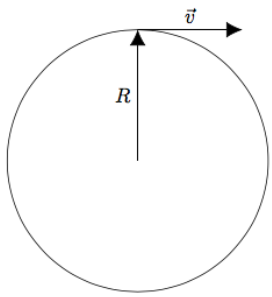
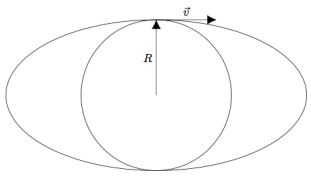


Figure 2

8) A spaceship moves around a planet in a circular orbit as shown in Fig. 2. At this instant, the spaceship's engines turn on for a time much shorter than the orbital period of the spaceship, and accelerate the spaceship in the direction of its velocity vector. The new orbit of the spaceship is most like:

a)



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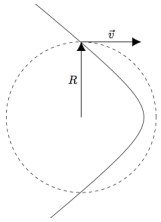
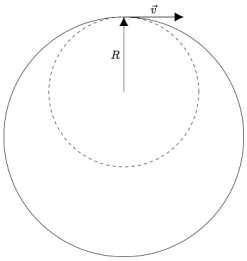
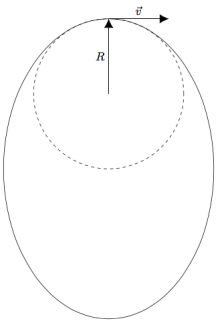


c)



d)



9) Electrons are fired towards a screen with two slits cut into it. A particle detector is placed behind the slits; the detector is moved to determine the number of electrons passing at different angles. The experiment is repeated twice, once with low energy electrons and once with high energy electrons. The density of electrons hitting the detector as a function of angle is plotted for the two experiments in Fig. 3 and Fig. 4.

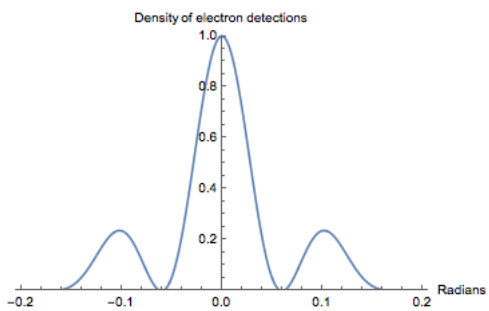


Figure 3: Experiment 1 (shown above)

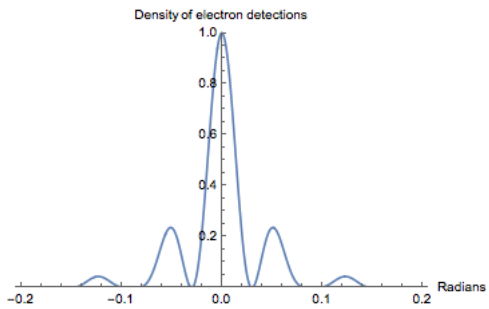


Figure 4: Experiment 2 (shown above)

Which of the experiments was performed with the high energy electrons, and which with low energy?

a) Experiment 1 was with low energy electrons, experiment 2 with high energy.

b) Experiment 1 was with high energy electrons, experiment 2 with low energy.

c) Both high and low energy electrons would produce the graph shown in experiment 1.

d) It is not possible to say which experiment was with high energy and which with low energy based on the graphs shown.

10) The dependence of the index of refraction of air on temperature and pressure is well approximated by

$$n(P,T) = 1 + 0.000293\frac{P}{P_0}\frac{T_0}{T},$$

where $T_0 = 300K$ and $P_0 = 1$ atm. Consider the image shown in Fig. 5. This is an image taken of a large ship on Lake Superior. The correct explanation for this phenomena is

a) There is turbulent air between the observer and the ship, leading to an inversion of the image.

b) There is a layer of warm air above a layer of cool air near the surface of the water.

c) There is a layer of hot air close to the water.

d) There is cold air held between two layers of warmer air.

Figure 5

11) Newtons law of cooling can be used to show that the temperature as a function of time takes the form $T(t) = A(1 - e^{-Bt})$. Measurements of the temperature of an object which has been removed from a freezer and placed in a warm room are shown in Fig. 6. Which of the following are the best estimates for the values of A and B?

a) $A = 20°C$ and $B = 1/5\,\text{min}^{-1}$

b) $A = 20°C$ and $B = 1/2\,\text{min}^{-1}$

c) $A = 15°C$ and $B = 5\,\text{min}^{-1}$

d) $A = 15°C$ and $B = 3\,\text{min}^{-1}$

e) $A = 15°C$ and $B = 1/3\,\text{min}^{-1}$

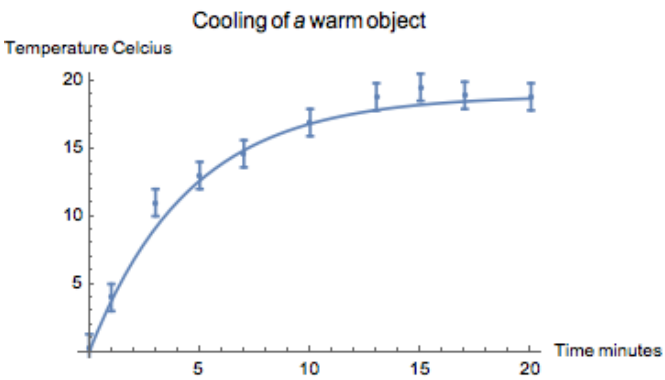


Figure 6

12) The expansion of a rod when heated is described by the equation $L(T) = L_0(1+\alpha\Delta T)$ where L_0 is the length of the rod at an initial temperature and ΔT is the change in temperature, and α is a coefficient that depends on the type of material used. Now suppose we have a ring with $\alpha = 10^{-5}/°C$ and a sphere with $\alpha = 0.5 \times 10^{-5}/°C$. The sphere is of radius $10.005cm$, the ring has an inner radius of $10.000cm$, both when measured at $20°C$. At what temperature does the sphere just fit through the ring?

a) $100°C$

b) $120°C$

c) $70°C$

d) $360°C$

e) $210°C$

13) Electromagnetic radiation with intensity (power per unit area) I exerts a pressure on a surface perpendicular to the radiation given by I/c. The sun has a radiation intensity of $1.38\,\text{kW/m}^2$ from where you will be launching. You are building a solar sail spaceship - a spaceship that uses a large thin sheet to use light pressure to accelerate. The material you are building your sail out of has a mass per unit area of $0.1\,\text{g/m}^2$, and you have a payload of $25\,\text{g}$. Approximately how large does your sail have to be to accelerate your ship at $2\,\text{cm/s}^2$?

a) $10\,\text{m}^2$

b) $20\,\text{m}^2$

c) $100\,\text{m}^2$

d) $200\,\text{m}^2$

e) $250\,\text{m}^2$

14) The work in rotational motion is given by:

a) Torque times angular frequency

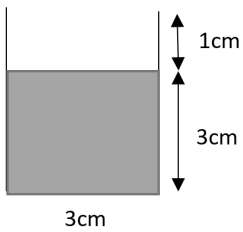
b) Torque times frequency

c) Torque times angular displacement in radians

d) Torque times angular displacement in degrees

e) Torque per unit time

15) A passenger of a car is holding a cylindrical cup of tea (shown below). The passenger keeps the cup held upright. Neglecting the vibration of the car, what is the maximum acceleration that the car can go without spilling any tea?



a) $\frac{g}{3}$

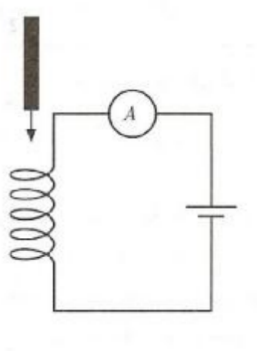
b) $\frac{g}{1.5}$

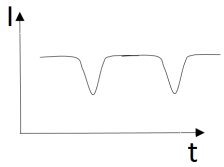
c) $1.5g$

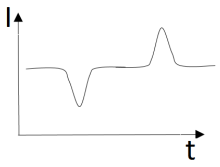
d) g

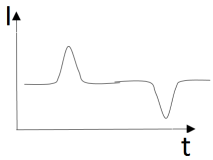
e) $3g$

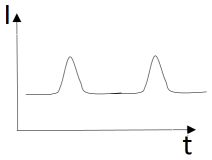
16) The circuit shown below is connected and left untouched until the current in the circuit become constant. You then insert an iron rod in the inductor shown below and take it out from the other end. Which graph best represents the current during this process?



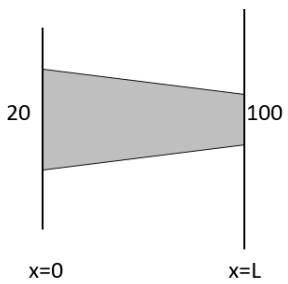
a) 

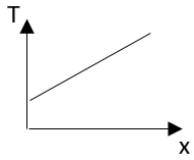
b) 

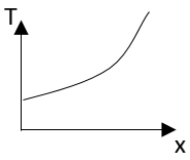
c) 

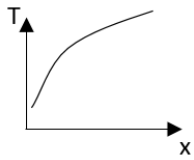
d) 

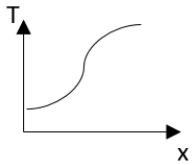
17) A conical, metal beam is placed between two constant temperature surfaces. The surfaces are at 20 and 100 degrees, as shown in the picture. Which one of the graphs below best represents the temperature along the center of the beam at equilibrium?



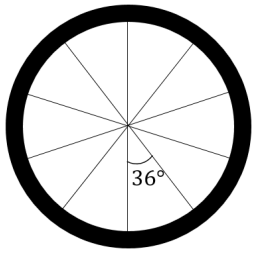
a) 

b) 

c) 

d) 

18) A video camera that takes 15 frames per second is filming the rotation of a bicycle wheel. If the bicycle wheel is rotating at 2 rotations per second and has 10 spokes, at what speed would it seem to be rotating in the movie?



a) 0.25 rotations per sec in the same direction as the actual rotation.

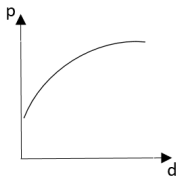
b) 0.25 rotations per sec in the opposite direction as the actual rotation.

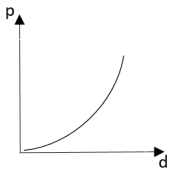
c) 0.33 rotations per sec in the same direction as the actual rotation.

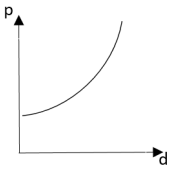
d) 0.5 rotations per sec in the same direction as the actual rotation.

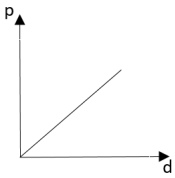
e) 0.5 rotations per sec in the opposite direction as the actual rotation.

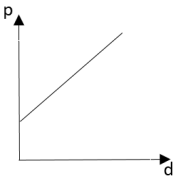
19) Assuming a constant temperature of the water in an ocean, which one of these graphs best represents the absolute pressure of the water as a function of depth below the water's surface? Take into account that water will compress as the pressure is increased.

a) 

b) 

c) 

d) 

e) 

20) Consider motion in only one dimension. An object with mass m_1 and initial speed $v_{1,i}$ in the direction of the positive x axis collides with a stationary object of mass m_2. The first object bounces back, moving with speed $v_{1,f}$ in the direction of the negative x axis. The second object has a final speed $v_{2,f}$. If the collision was perfectly elastic, which of the following *must* be true?

a) $m_1 = m_2$

b) $m_1 > m_2$

c) Such a collision is impossible

d) $m_1 < m_2$

e) $|v_{1,i}| < |v_{1,f}|$

21) A solid ball of radius R has a mass of 2 kg and is initially stationary on a flat surface. It is then hit by a 5 g bullet initially traveling at 1000 m/s. In a one-in-a-million shot, the bullet hits the ball perfectly head-on and sticks inside it. Due to the high friction with the surface the ball eventually reaches the state of rolling with no slipping. What is the final speed of the ball at this state? (The moment of inertia of a solid sphere is $I = \frac{2}{5}mR^2$)

a) 0 m/s

b) 0.5 m/s

c) 0.714 m/s

d) 1.79 m/s

e) 2.5 m/s

22) Two objects, A and B, appear the same length when A is stationary and B is moving with speed $(3/5)c$ along its length. In the frame of reference where B is stationary and A is moving, what is the ratio of their lengths?

a) $L_A/L_B = 5/4$

b) $L_A/L_B = 25/16$

c) $L_A/L_B = 4/5$

d) $L_A/L_B = 9/25$

e) $L_A/L_B = 16/25$

23) An inflated balloon, filled with a gas of temperature T, is held in a room with the same temperature. If we make a small hole on the side of the balloon and let the gas escape, which statement is true about the temperature T' of the gas right after leaving the balloon?

a) $T' > T$

b) $T' = T$

c) $T' < T$

24) It is desired that a flexible copper wire passes in a straight line between two supports. The wire has a mass M, a length L and carries a current I. However, due to the force of gravity on the wire it will tend to sag between the two supports(Fig. 5). It is possible to correct for this sagging by adding a magnetic field to the region between the supports. To do this, the magnetic field should be

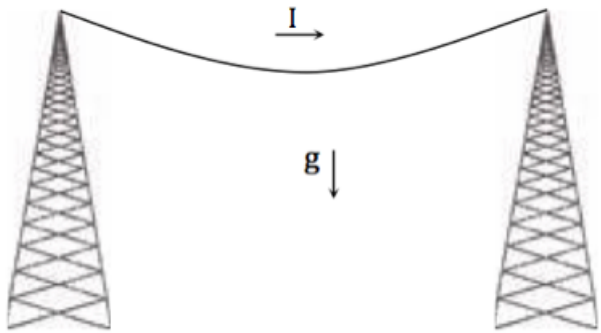


Figure 7

a) Into the page and of magnitude $\frac{Mg}{LI}$

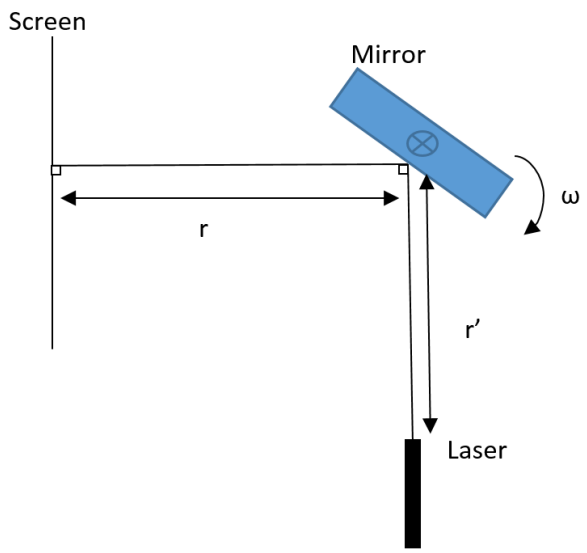
b) Out of the page and of magnitude $\frac{Mg}{LI}$

c) Into the page and of magnitude $\frac{Mg}{2LI}$

d) Out of the page and of magnitude $\frac{Mg}{2LI}$

e) Into the page and of magnitude $\frac{MLg}{2I}$

25) A rotating mirror is reflecting a laser light on a screen. What would the speed of the spot illuminated by the laser light be at the instance shown in the picture below, if the angular speed of the rotation of the mirror is ω?



a) $\omega r'$

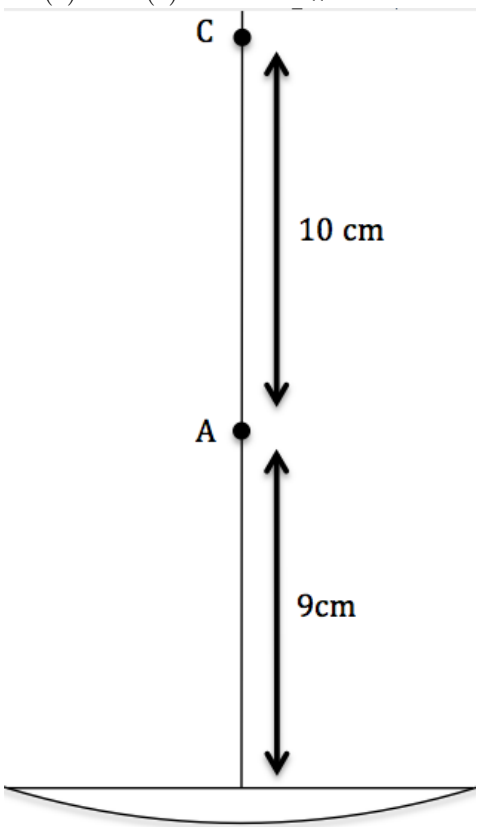
b) $2\omega r'$

c) $\omega(r + r')$

d) ωr

e) $2\omega r$

1) A circular mirror of radius R = 20 cm and center C is filled with a transparent liquid up to 1 cm of height. What is the refractive index of this liquid if the image of point A falls on itself? You may use the small angle approximation: $\tan(\theta) = \sin(\theta) = \theta$ for $\theta \ll 1$.

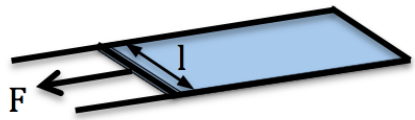


2)

The 2 photos above show a woman jumping on a Pogo Stick. In the photograph on the left she is in the air at her highest point whereas in the photograph on the right she is at her lowest point (notice that at this time the spring is compressed). The picture on the far right shows how the pogo stick is built. The woman is 168 cm tall and weighs 60 kg.

Calculate the full period of her jumps and plot with appropriately marked scales the height of her center of gravity as a function of time. Assume that the woman keeps her body stationary with respect to the pogo stick.

3) The tension of the surface film of a liquid caused by the attraction of the particles in the surface layer of the liquid is called surface tension. This force is responsible for the spherical shape of soap bubbles in the air and can be modeled as $F = \sigma \cdot l$ where σ is the surface tension constant of the liquid and l is the length of the cross section of the surface. For example: In the picture shown below, a force of $F = 2 \cdot \sigma l$ is required to hold and expand the thin layer of bubble between the two rods held at a distant l (notice that the factor of 2 appears because the bubble has two surfaces).



a) An astronaut pours some water in the air on a space station (no gravity environment) and notices that due to its surface tension, the liquid turns into a ball of radius 5 cm. What is the pressure difference inside and outside of the water ball? ($\sigma_{water} = 0.073\,\mathrm{N/m}$)

b) The astronaut notices that if she connects two water-balls with radii of $r_1 = 2\,\mathrm{cm}$ and $r_2 = 5\,\mathrm{cm}$ with a thin straw of diameter $D = 1\,\mathrm{mm}$ and length $L = 5\,\mathrm{cm}$, water will flow from one ball to the other ball. Find the direction and the magnitude of the average speed V_{av} of the water between balls in terms of r_1, r_2 at the instant in which they are connected by the straw. Assume that the balls remain almost spherical.

HINT: The pressure drop in a pipe is given by $\delta p = 32\mu L V_{av}/D^2$, where $\mu_{water} = 0.001002\ \mathrm{N \cdot s/m^2}$ is the dynamic viscosity of water.

c) Estimate how long it would take for one ball to completely absorb the other.

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