BOSWELL-BÈTA

James Boswell Exam

physics vwo

Date:	example exam
Time:	3 hours
Number of questions:	5
Number of subquestions:	24
Number of appendices:	3 (2 for question 1 and 1 for question 4)
Total number of points:	74

- Write your name on each sheet.
- Answer each question on a separate sheet.
- For every question, show how you obtained your answer by means of a calculation or motivation.
- No points will be awarded to an answer without an explanation.
- Answers with an error in the significance of more than 1 digit in the quantities or units or a combination thereof will result in deduction of one point per separate question.
- Write legibly and in ink. Use of tipp-ex and such or writing in pencil is not allowed.
- Only use a pencil for making drawings.
- Possible additional data can be found in BINAS 5th edition.

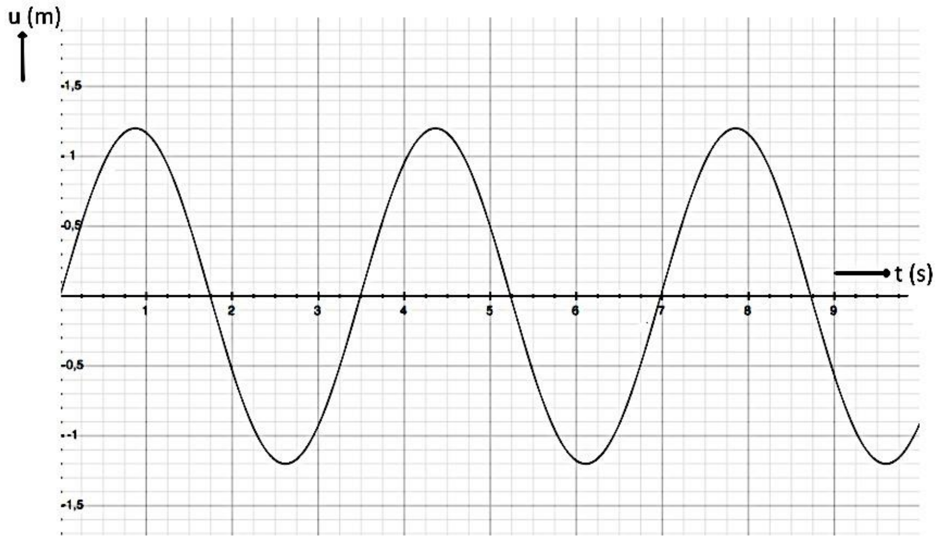
Question 1 Ski lift

Modern ski lifts move, when the skiers are entering the lift, with a velocity of roughly 0.80 m/s, subsequently accelerating to transport the skiers. In the picture on the right, the acceleration of one of the gondolas is clearly visible by the "slanting" of the gondola. This picture can also be found in the appendix. The gravitational force has already been indicated in the appendix by a black arrow. The point of application of this arrow is located in the centre of gravity of the gondola. The scaling in the picture is such that a vector of 1 cm represents a force of 500 N. In addition to the gravitational force, a tension force is also working in the bar which suspends the gondola.

a. (3p) Using the figure in the appendix, determine the mass of the gondola.

b. (4p) Using the figure in the appendix, determine the tension force in the bar that suspends the gondola. To do this, first construct the direction of the resulting force on the gondola in the figure on the appendix.

Due to a malfunction, the gondola suddenly stops. Because it has a certain velocity, it will perform a harmonic oscillation. The following diagram shows the displacement of the centre of gravity of the gondola as a function of time. This diagram can also be found in the appendix.



The frequency of this oscillation is given by $f = \frac{1}{2\pi}\sqrt{g/l}$ in which l represents the distance of the anchor point to the centre of gravity of the gondola and g represents the gravitational acceleration.

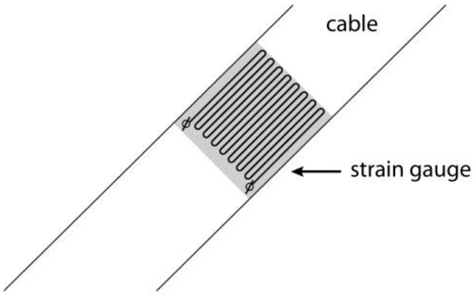
c. (3p) Using the diagram in the appendix, determine distance l.

d. (3p) Determine the maximum velocity of the gondola when it is swinging to and fro.

Question 2 Strain gauge

To make sure not too much strain is placed on a bridge, sensors are used. Such a sensor contains a so-called 'strain gauge', which is glued to one of the cables of the bridge. A long, thin constantan wire is incorporated into this strain gauge. See figure 1.

figure 1

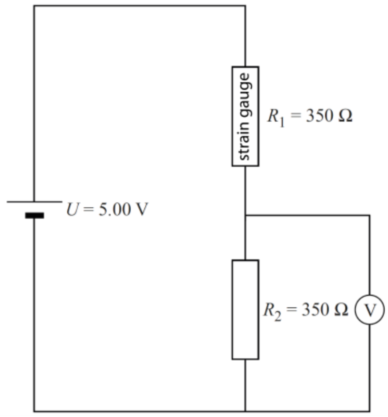


This wire has a resistance of 350 Ω and a diameter of 40 μm.

a. (4p) Calculate the length of the constantan wire.

When the bridge supports a lot of traffic, the cable stretches a little. The strain gauge then stretches by the same percentage as the cable. When stretching in this manner, the resistance of the strain gauge changes. By measuring this change in resistance, it can be determined whether the cable is stretching too much.
When the gauge stretches, the resistance of the constantan wire increases.

figure 2



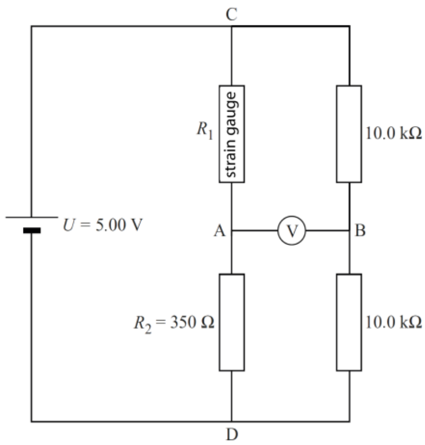
b. (2p) Give two reasons for this.

The change in resistance of the strain gauge can be determined by means of the circuit in figure 2. When the resistance of the strain gauge increases by 1.0 Ω, the voltage indicated by the voltmeter changes by less than half a per cent.

c. (3p) Demonstrate this.

To better measure the change in resistance, the circuit in figure 3 is used. When the strain gauge is not stretched, the voltmeter indicates 0.000 V.

figure 3



d. (2p) Explain this.

As soon as the strain gauge stretches, the voltmeter does indicate a voltage. See the diagram in figure 4.

e. (2p) Explain whether in this case the voltage in A (see figure 3) will be higher or lower than in point B.

figure 4

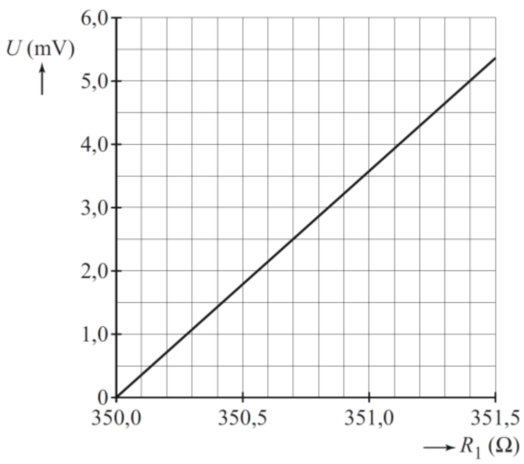
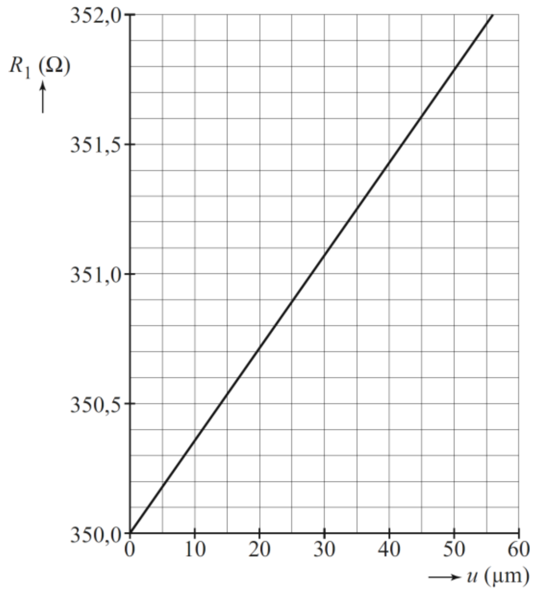


figure 5



The strain gauge has a length of 6.1 cm and has been glued to a bridge cable of 198 m in length. The diagram of figure 5 shows the relationship between the resistance and the stretching of the strain gauge. If the cable of the bridge stretches 12 cm due to too much traffic, an alarm sounds.

f. (3p) Determine at which voltage the alarm sounds.

Question 3 The greenhouse effect

Many people associate carbon dioxide (CO_2) with greenhouse gases. However, water (H_2O) in the form of water droplets or water vapour contributes far more (roughly 90%) to the greenhouse effect than carbon dioxide (roughly 10%). This is mainly due to the percentage of water in the atmosphere being far larger than the percentage of carbon dioxide. Both water and carbon dioxide have the characteristic that they 'retain' heat. This is also what happens in a greenhouse, hence the name 'greenhouse gases'.
In this question, we examine why greenhouse gases do what they do (namely retain heat) and what effect greenhouse gases have on the temperature of the earth.

The earth receives energy from the sun: every second 1.40 kJ per m^2 earth surface (measured perpendicular to the direction of the solar radiation). Of this energy, on average 30% is directly reflected back into space (mainly by water, snow, and ice surfaces).

a. (4p) Demonstrate that the total <u>net</u> solar radiation power that the earth receives is equal to $1.25 \cdot 10^{17}$ W.

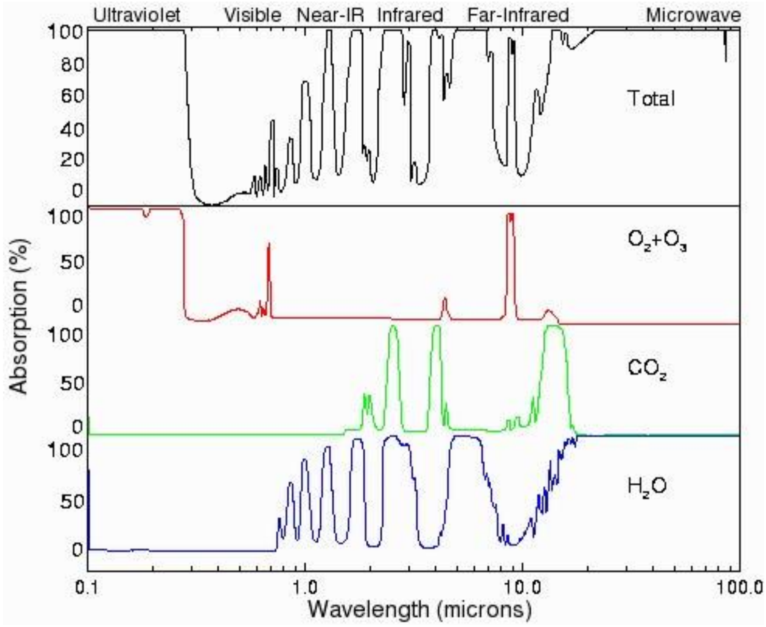
Because the temperature of the earth is constant, the earth needs to radiate as much energy as it receives.

b. (3p) Show that the (average) temperature of the earth would be below the freezing point of water if the earth was a black body and if it would radiate as much energy as it net receives.

The earth's surface has an average temperature of 15 °C, which is considerably warmer than you would expect. A possible explanation is that energy is absorbed in the atmosphere, which is then radiated back to the earth's surface.

c. (3p) Calculate the wavelength in μm at which the most radiation energy is emitted by the earth, assuming that the temperature of the earth is 15 °C.

The absorption and back radiation of electromagnetic radiation happens due to the so-called greenhouse gases.



The diagram shows the absorption spectrum of different gases. The horizontal wavelength scale is given in *micron* (=μm).

d. (2p) Using the diagram, explain that both H_2O and CO_2 are greenhouse gases.

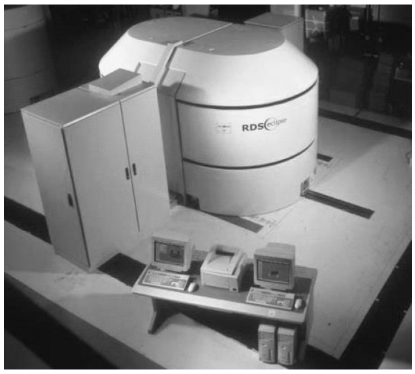
In the absorption spectrum of CO_2 you can see three strong lines with wavelengths 2.5 μm, 4.0 μm and 12 μm.

Assume that in a single CO_2 molecule, one electron is located that can freely move within the molecule, and assume that the CO_2 molecule is in the ground state ($n = 1$). The absorption lines could then belong to the energy transitions of $n = 1 \rightarrow 2$, $n = 1 \rightarrow 3$ *en* $n = 1 \rightarrow 4$.
We now assume that the 2.5 μm line belongs to the greatest energy transition ($n = 1 \rightarrow 4$).

e. (4p) Calculate, with the particle-in-box model, the dimensions of the CO_2 molecule in nm.

f. (4p) Carry out the following tasks:
- Calculate the ratios of the values of the energy transitions that follow from the wavelengths of the diagram (so $E_{n=1\rightarrow 2}:E_{n=1\rightarrow 3}:E_{n=1\rightarrow 4}$).
- Subsequently calculate the ratios of the values of the mentioned energy transitions that follow from the particle-in-box model.
- Finally check whether the ratios from the model fit the ratios of the diagram.

Question 4 Cyclotron



In hospitals, cyclotrons are used to make radioactive isotopes which are used for diagnostic purposes. See the picture.
A cyclotron is a device, which consists of two hollow D-shaped copper drums a small distance apart, as schematically indicated in figures 1 and 2. These figures are not to scale. The entire setup is located in a vacuum.

figure 1

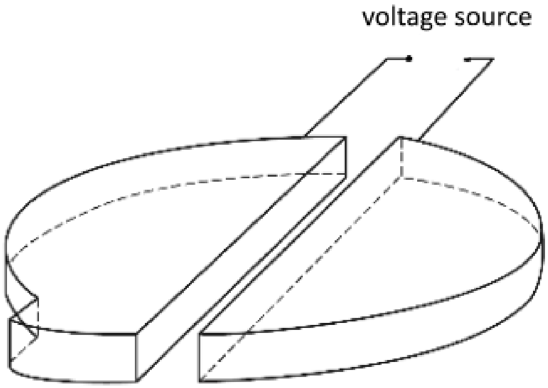
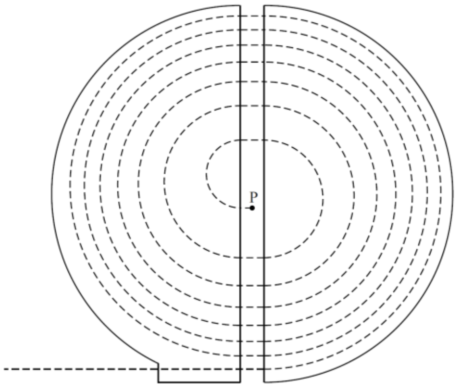


figure 2



An electric field is located in the space between the two drums. Because the drums are connected to an alternating voltage source, this field keeps changing direction.
In the middle (see figure 2), a proton source, P, is located. The protons are accelerated in the electric field and end up in one of the drums.
Perpendicular to both drums there is a homogeneous magnetic field, which causes the protons to trace a semi-circular path at a constant speed. The path of the proton is indicated by the dotted line. An enlarged version of figure 2 can be found in the appendix.

a. (3p) Carry out the following tasks:
- In the figure in the appendix, indicate the direction of the proton's speed and the direction of the Lorentz force in points 1 and 2.
- Explain how the magnetic field is directed in points 1 and 2.

A proton traces a semi-circular path in a drum. For the time *t* that is needed to trace such a semi-circular path, the following holds true:

$$t = \frac{\pi m}{Bq}$$

Here:
- m is the mass of the proton;
- B is the strength of the magnetic field;
- q is the charge of the proton.
-

b. (4p) Deduce this using formulas from Binas.

Every time that a proton enters the space in between the two drums after having completed a semi-circle, the electric field will have reversed direction, so that it is in the right direction and the proton receives the same amount of kinetic energy again. The velocity of the proton as a function of time that follows from this has been sketched in the diagram of figure 3.

figure 3

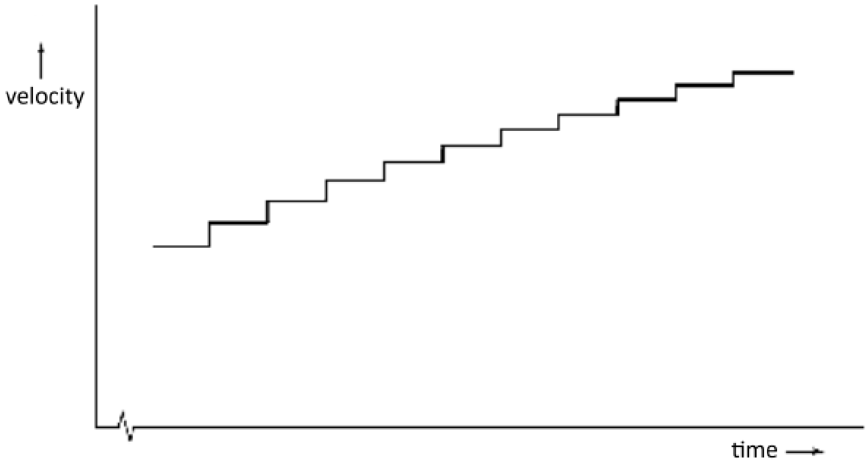


Figure 3 shows two characteristics:
- the time-span of each step in the drums is the same every time;
- the increase in velocity decreases for every step between the drums.

c. (2p) Explain for both characteristics why these are true.

The strength of the magnetic field is 1.5 T. The alternating electric field between the two empty spaces is caused by an alternating voltage.

d. (3p) Calculate the frequency of this alternating voltage.

Question 5 Supernova explosion

The following message appeared in the NRC (New Rotterdam Newspaper) in April 2016:

In the last ten million years, many supernova explosions have occurred in the vicinity of our solar system at distances of up to 300 light years from earth. This is indicated by the presence of minuscule amounts of radioactive iron-60 in the oceanic crust.
Most of the iron-60 can be found in earth layers which are 1.5 to 3.2 million years old, but also 7.5-million-year-old layers show a peak in radioactive iron deposition.
In such a supernova explosion, large quantities of star matter, which also contains the radioactive isotopes iron-60, aluminium-26, and beryllium-10, are blasted into space. When a supernove explosion occurs close enough to the earth, tiny amounts of those isotopes end up on our planet.

The following details are known about iron-60:
Type of decay: β^- decay *Half-life: 2.62×10^6 years* *Decay energy: 237.18 keV*

This matter is emitted by the star at a velocity roughly 10% of the speed of light.

a. (2p) Demonstrate that hardly any of the iron-60 emitted by the star has decayed when it reaches the earth.

b. (3p) Calculate the percentage of the original iron-60 still remaining after 7.5 million years.

c. (3p) Give the decay equation of iron-60.

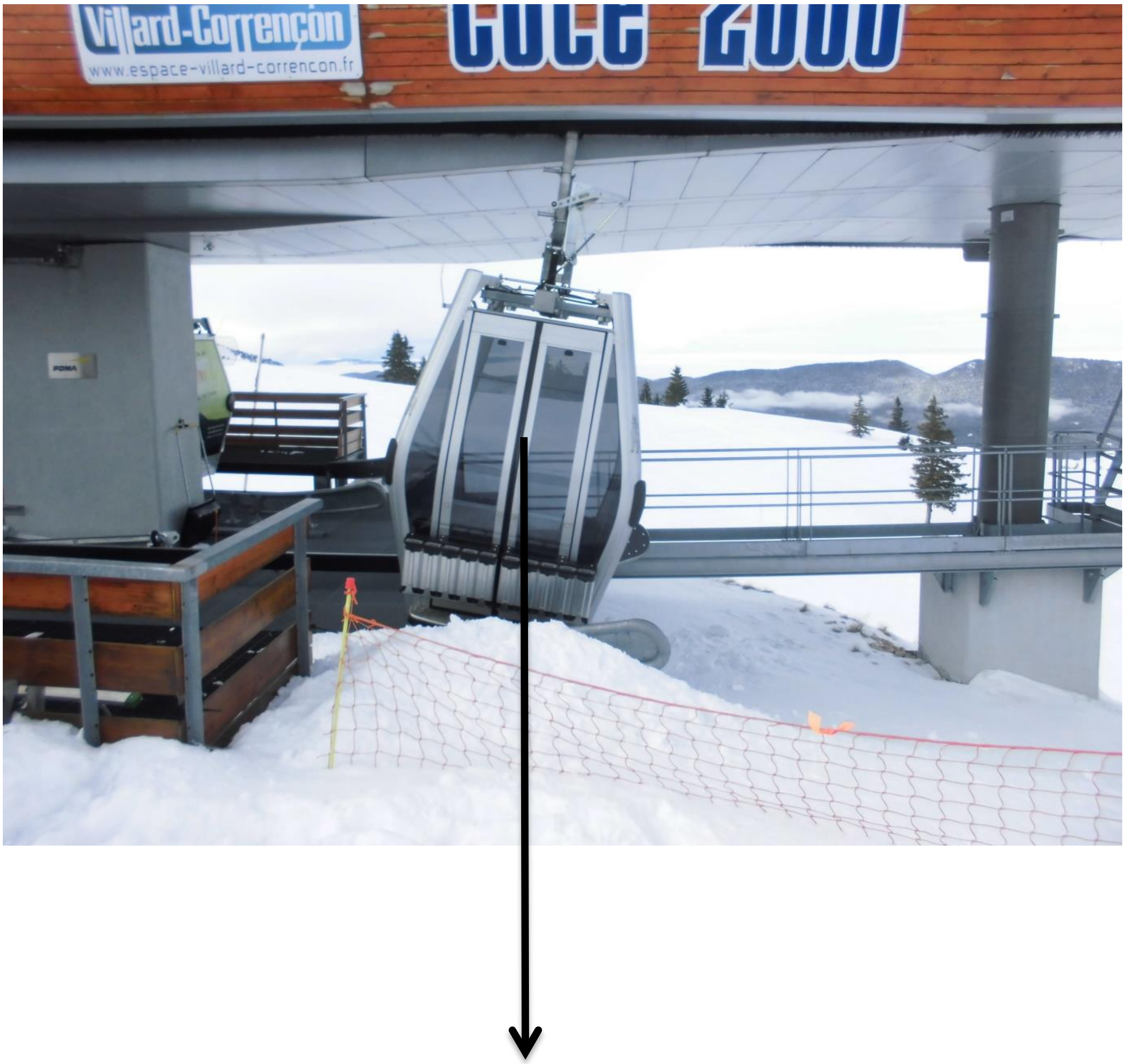
To be able to carry out a reliable measurement of the material in the seabed, a minimal activity due to iron-60 of 10 Bq is required.

d. (4p) Calculate the minimum amount of iron-60 (in grams) that a sample of the material needs to contain.

THE END

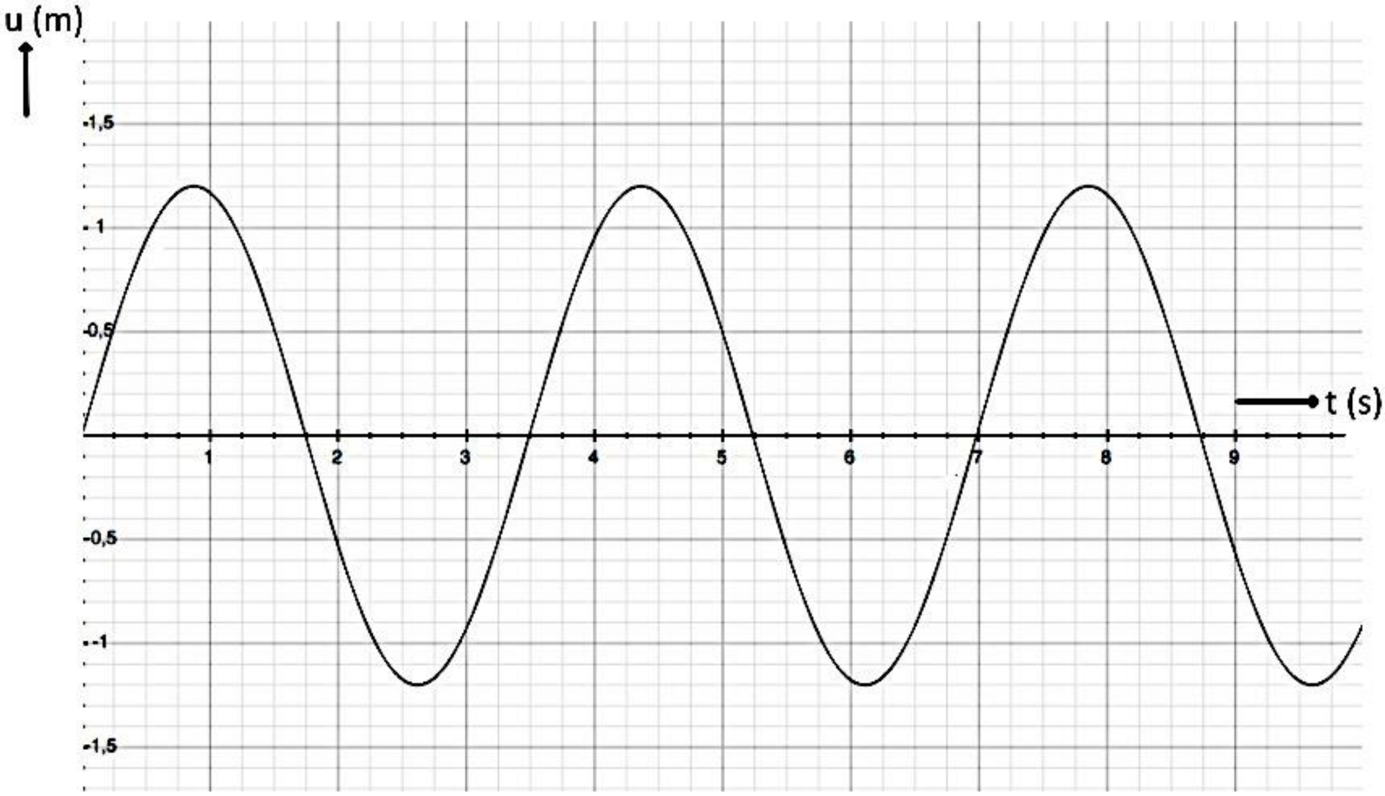
APPENDIX FOR QUESTION 1

Name: ……………………………………….



APPENDIX FOR QUESTION 1

Name: ……………………………………….



APPENDIX FOR QUESTION 4

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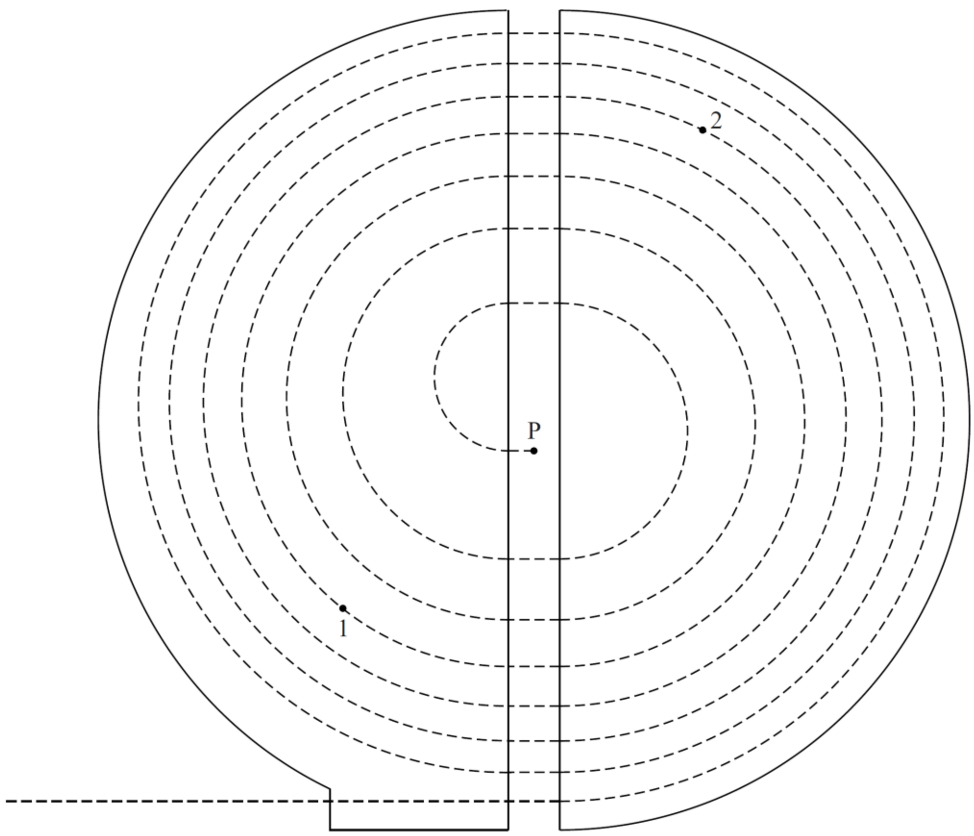
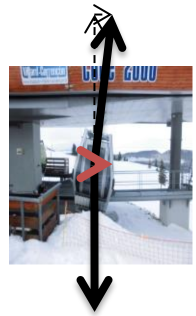


Question 1 Ski lift

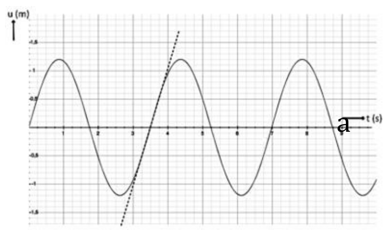
a. The length of the arrow representing the weight is 8.6 cm, corresponding to $8.6 \times 500 = 4.3 \cdot 10^3$N. So the mass is $\frac{4.3 \cdot 10^3}{9.81} = 4.4 \cdot 10^2$ kg.



b. See the figure on the right: the length of the tension force is 8.4 cm, corresponding to $8.4 \times 500 = 4.2 \cdot 10^3$N.

c. The time period $T = 3.5$ s (from the diagram). So $f = \frac{1}{T} = \frac{1}{3.5} = \frac{1}{2\pi}\sqrt{\frac{g}{l}} \Rightarrow l = 3.0$ m.

d. $v_{\text{max}} = \frac{2\pi A}{T} = \frac{2\pi \times 1.2}{3.5} = 2.2$ m/s
Alternatively, draw tangent to find the maximum velocity.



Question 2 Strain gauge

a. $R = \rho\frac{l}{A} \Rightarrow l = \frac{RA}{\rho} = \frac{350 \times \pi \times (20 \cdot 10^{-6})^2}{45 \cdot 10^{-6}} = 0.98$ m

b. Stretching the stain gauge increases l and decreases A. As a result $R = \rho\frac{l}{A}$ decreases.

c. The potential difference across R_2 is 2.5 V when the strain gauge is not stretched. When the resistance of the strain gauge increases by 1 Ω, the potential difference across R_2 becomes $\frac{350}{350+351} \times 5 = 2.496$ V. This is 0.004 less, or $\frac{0.004}{2.5} \times 100\ \% = 0.16\ \%$.

d. Both V_A and V_B are 2.5 V because $R_1 = R_2$ and the other two resistances are equal too. So $U_{AB} = 0$ V.

e. When R_1 increases, U_{CA} increases, so V_A becomes smaller than 2.5 V. Because V_B remains the same, V_A will be lower than V_B.

f. The strain gauge stretches $\frac{6.1 \times 0.12}{198} = 37$ μm. Figure 5 gives $R_1 = 351.3$ Ω, and then according to figure 4 the voltage is 4.7 mV.

Question 3 The greenhouse effect

a. The power received is $0.7 \times 1.40 \cdot 10^3 \times \pi R^2$, and $R = 6.378 \cdot 10^6$ m. This gives $1.25 \cdot 10^{17}$ J/s.

b. Stefan-Boltzmann's law: $P = \sigma A T^4 \Rightarrow 1.25 \cdot 10^{17} = 5.67 \cdot 10^{-8} \times \pi \times (6.378 \cdot 10^6)^2 \times T^4 \Rightarrow T = 256\ \text{K} = -17\ °\text{C}$.

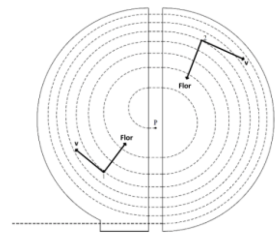
c. Wien's law: $\lambda_{\text{max}} T = k_W \Rightarrow \lambda_{\text{max}} = \frac{2.90 \cdot 10^{-3}}{288} = 10.1\ \mu$m.

d. There is no absorption of visible light, the earth radiates infrared light and there is a lot of absorption in the infrared part of the spectrum..

e. $E_{\text{ph}} = \frac{hc}{\lambda} = \frac{6.63 \cdot 10^{-34} \times 3.00 \cdot 10^8}{2.5 \cdot 10^6} = 7.96 \cdot 10^{-20}$ J.
$= E_4 - E_1 = (4^2 - 1^2)\frac{h^2}{8mL^2} \Rightarrow L = 3.4$ nm

f. The ratios according to the particle-in-a-box model are $2^2 - 1^2 : 3^2 - 1^2 : 4^2 - 1^2 = 3:8:15$.
The ratios of the energies are the same as the ratios of the reciprocal wavelengths so 1/12:1/4.0:1/2.5=0.08333:0.25:0.5, which is 3:9:14 (multiply by 3/0.0833). So they agree quite well.

Question 4 Cyclotron



a. The B-field points out of the paper (LH-rule).

b. $F_L = F_{cp} \Rightarrow Bqv = \frac{mv^2}{r} \Rightarrow v = \frac{Bqr}{m}$
Furthermore $v = \frac{2\pi r}{T} = \frac{2\pi r}{2t} = \frac{\pi r}{t}$
So $\frac{\pi r}{t} = \frac{Bqr}{m}$ and this gives $t = \frac{\pi m}{Bq}$

c. The time t does not depend on r, see formula.
The change ΔE_k is constant for every step between the drums. Since $E_k = \frac{1}{2}mv^2$, so $\Delta(v^2)$ is constant for every step and Δv decreases.
Alternatively: each step takes less time because v increases, so $\Delta v = a\Delta t$ decreases for every step (a is constant because F_{el} is constant).

d. $f = \frac{1}{2t} = \frac{Bq}{2\pi m} = \frac{1.5 \times 1.6 \cdot 10^{-19}}{2\pi \times 1.67 \cdot 10^{-27}} = 23$ MHz

Question 5 Supernova explosion

a. 300 light year with a speed of $0.1c$ takes 3000 year. This is approximately $\frac{1}{1000}t_h$ so hardly anything has decayed.

b. $100 \cdot \left(\frac{1}{2}\right)^{7.5/2.62} = 14\ \%$

c. ${}^{60}_{26}\text{Fe} \rightarrow {}^{60}_{27}\text{Co} + {}^{\ 0}_{-1}\text{e}$

d. $A = \ln(2)\frac{N}{t_h}$ so
$N = \frac{A \cdot t_h}{\ln(2)} = \frac{10 \times (2.62 \cdot 10^6 \times 365 \times 24 \times 3600)}{\ln(2)} = 1.2 \cdot 10^{15}$
The mass of a Fe-60 nucleus is 60 u, so the mass of the iron is $1.2 \cdot 10^{15} \times (60 \times 1.66 \cdot 10^{-27}) = 1.2 \cdot 10^{-10}$ kg $= 1.2 \cdot 10^{-7}$ g.