PHYSIKSOLYMPIAD
LËTZEBUERG 2018

Final : Experimental part

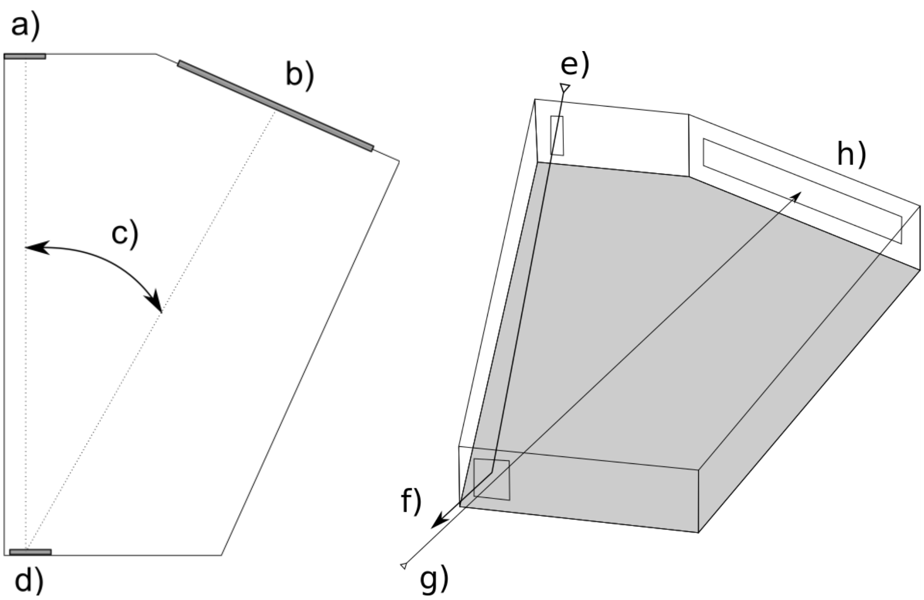
Study of light emission

Introduction

Light is a physical phenomenon that manifests itself in microscopic processes at the atomic scale as well as in the field of astronomy where light was, until the detection of gravitational waves, our only source of information on distant stars and galaxies. During this practical part, you will build a spectrometer to break down a light beam into the colors that compose it. Spectral analysis of light from various known sources will allow you to establish a calibration curve that you are going to use to identify an unknown chemical element.

Experimental apparatus

First of all, you have to build the spectrometer, which has an entrance slot (width 0.2-0.3mm) (a), a millimeter scale covered with tracing paper (b). The light that enters is diffracted by a diffraction grating (1000 lines per mm) (d) on average according to a diffraction angle (c).



1. Cut out the cardboard using the templates. Watch your fingers!

2. Cut black paper, transparent graph paper, tracing paper, and the diffraction grating according to the sizes provided in the templates.
3. Glue the base and sides of the spectrometer together, then glue the grating to its position d). Check the orientation of the grating, making sure that the diffracted beam f) is in line of sight g) -> h).
4. Close the spectrometer by gluing the rest of the pieces. The entrance slit and the scale are glued to the outside of the box.

Calibration

Use all the electric discharge lamps of known elements to establish a calibration curve of λ (wavelength of light) as a function of x (apparent position of the spectral lines on the graph paper). Tables showing the emission lines of the various elements are used to determine the wavelength of the most intense lines.

Spectrum analysis of an unknown gas

The spectrum of light that comes from the stars contains chemical information about their composition. The wavelengths of an unknown source are measured using the calibration curve established in the previous point.

It is assumed that the emission of light is due to the transition of an electron from an electronic layer n_2 to a lower electronic layer n_1. In his atomic model, Niels Bohr calculates the energies of the n-th atomic orbital with the formula:

$$E_n = k \cdot \frac{Z^2}{n^2}$$

where Z is the electric charge of the atomic nucleus.

Thus the energy of the photons emitted corresponds to the difference between two levels:

$$\Delta E = \frac{hc}{\lambda} = kZ^2 \cdot \left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right)$$

It is assumed that the base level is known: $n_1 = 2$ et $n_2 = 3,4,5$ ...

Using a linear regression, determine the factorkZ^2 and$Z$knowing that$k = 13,6eV$.

Report

Your report should contain:

- A description of the observations.
- A table with the measurements.
- An estimation of the measurement errors on x (to be indicated on the calibration curve by error bars).
- The graphics made.
- All the calculations you make.
- Evaluation of the results: Conclusion on the chemical nature of the unknown element.
- How could the uncertainty of measurements be reduced?

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Final: Theoretical Exam

24/04/2018

Instructions:

- Show your work.
- Write your answers on the intended pages.
- You may use both sides of the answer sheets.
- Write your participant number on each page.

Formulas

Kinematics (UAM)

$x = \frac{1}{2}at^2 + v_0 t + x_0$

$v = at + v_0$

$v^2 - v_0^2 = 2a(x - x_0)$

Forces

$F = ma$

$F_f \leq \mu N$

Work, Energy, Power

$W = Fd\cos\theta$

$E_{cin} = \frac{1}{2}mv^2$

$E_{pes} = mgh$

$E_{el} = \frac{1}{2}kx^2$

$P = \frac{W}{t} = Fv$

Momentum

$p = mv$

$F = \frac{\Delta p}{\Delta t}$

Thermal concepts

$Q = mc\Delta\theta$

$Q = mL$

Ideal gas

$p = \frac{F}{A}$

$pV = nRT = Nk_B T$

$E_K = \frac{3}{2}k_B T$

Oscillations and waves

$T = \frac{1}{f}$

$c = f\lambda$

$T = 2\pi\sqrt{\frac{l}{g}}$

$T = 2\pi\sqrt{\frac{m}{k}}$

Electricty

$I = \frac{Q}{t}$

$F = k \cdot \frac{q_1 q_2}{r_2}$

$V = \frac{W}{q}$

$E = \frac{F}{q}$

$V = RI$

$P = VI = RI^2 = \frac{V^2}{R}$

$R = R_1 + R_2 + \cdots + R_n$

$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$

$\rho = \frac{RA}{L}$

Electro-magnetism

$F = qvB\sin\theta$

$F = BIL\sin\theta$

Circular motion

$v = \omega r$

$a = \frac{v^2}{r}$

Gravitation

$F = G\frac{mM}{r^2}$

$g = \frac{F}{m}$

Quantum physics

$E = hf$

$\lambda = \frac{hc}{E}$

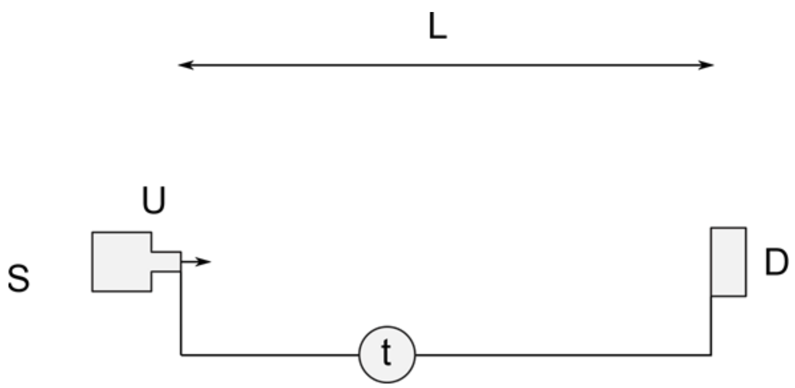
Optics

$n_1 \sin\alpha_1 = n_2 \sin\alpha_2$

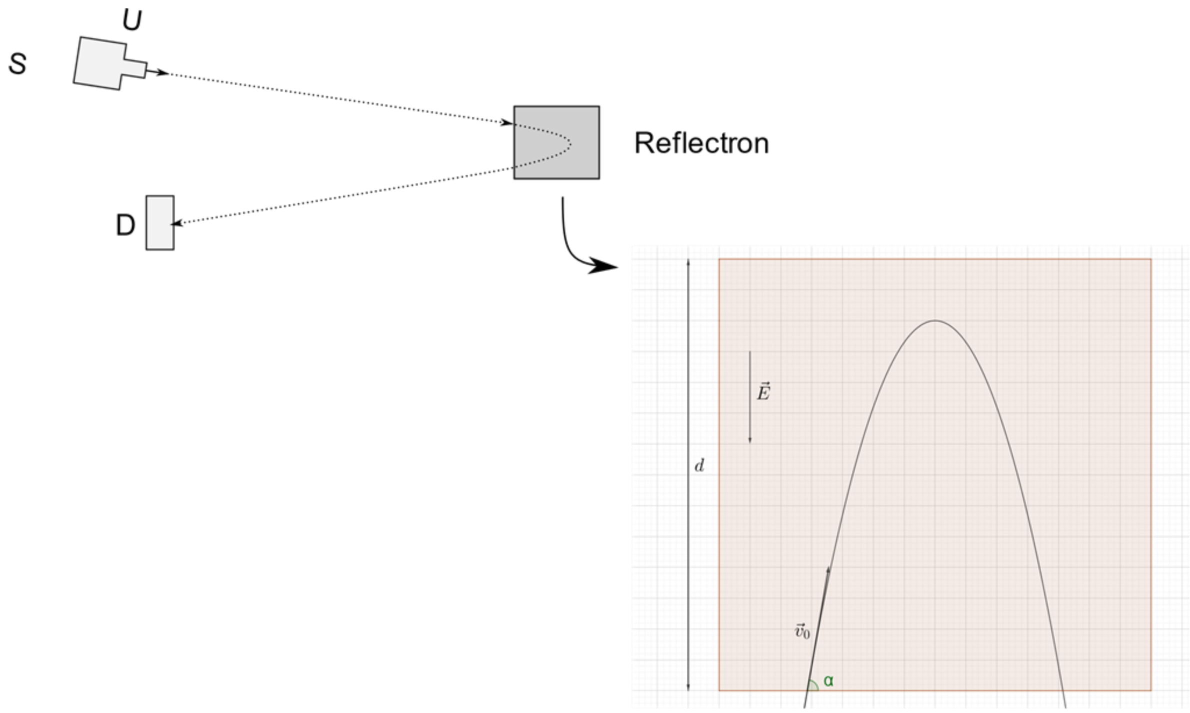
$\frac{1}{q} + \frac{1}{p} = \frac{1}{f}$

Question 1: Time-of-flight mass spectrometry (ToF-SIMS)

A source of ions (S in the diagram below) emits ions $^{28}Si^+$ and $^{29}Si^+$. These ions are accelerated inside the source by a voltage U. The ions then travel through an evacuated tube of length L, in which no electric field prevails before arriving at a detector D which makes it possible to measure the travel time t.



1. Give an expression of the mass *m* of the ion according to the parameters *U, L, t* and *q* (the electric charge of the ions). (4P)
2. For a tube length L = 2 m, a voltage U = 2 kV, determine the minimum temporal resolution Δt that the device must have in order to differentiate between the two isotopes of silicon. $(1e = 1{,}602 \cdot 10^{-19}C)$. (2P)
3. Will the temporal resolution found be sufficient to identify the isotopes of iron $^{56}Fe^+$ and $^{57}Fe^+$? Explain qualitatively. (3P)
4. More sophisticated flight time analysers use, in addition to the flight tube, an electrostatic mirror called "reflectron". It is a region with a uniform electric field $\vec{E}$ which deflects the ions. Where $E = \frac{U}{d}$:



Calculate the travel time t of the ions in the uniform electric field of the reflectron and the equivalent length L 'of a straight flight tube without the reflectron (i.e. having the same travel time). (8P)

(Data: U = 2 kV, d = 20 cm, α = 80 °, m = 28 amu, q = 1e)

5. The ions are not all emitted from the source with exactly the same energy E_0. Some exhibit slightly different energies $E = E_0 + \Delta E$ where $\Delta E \ll E_0$. What is the effect of this initial energy distribution on the flight time and the differentiation capacity of the device? Explain qualitatively! (3P)
6. Explain qualitatively how the reflectron can compensate for this negative effect. (2P)

Answer:

Question 1: Time-of-flight mass spectrometry (ToF-SIMS) Number:____

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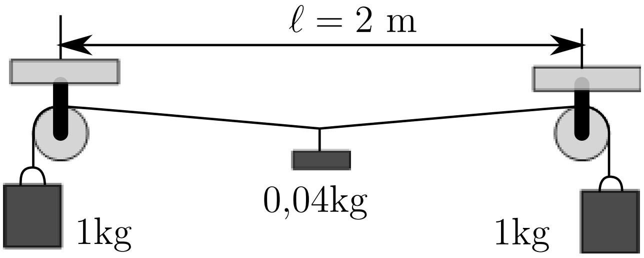
Question2: Oscillations

The oscillations of a system are called harmonic if the acceleration, therefore the restoring force F_R, is proportional to the displacement about its equilibrium position.

A small mass of 40 g is kept suspended between two pulleys by two M weights of 1 kg each as indicated below. The distance l between the two pulleys is equal to 2 m.



The small mass m is pulled down and released. It is free to oscillate around its equilibrium position. If the amplitude of the oscillations is small, the length of the string can be considered as being constant and the oscillations made by the two weights is negligible.

a) Draw on the figures attached to the following page the forces acting on the small mass (4P)
   - when it is in balance and
   - when it performs vertical oscillations.

b) Show that the acceleration of the mass is given by $a = -\frac{2Mg}{mb} \cdot x$

   where $b = \frac{\ell}{2}$ (8P)

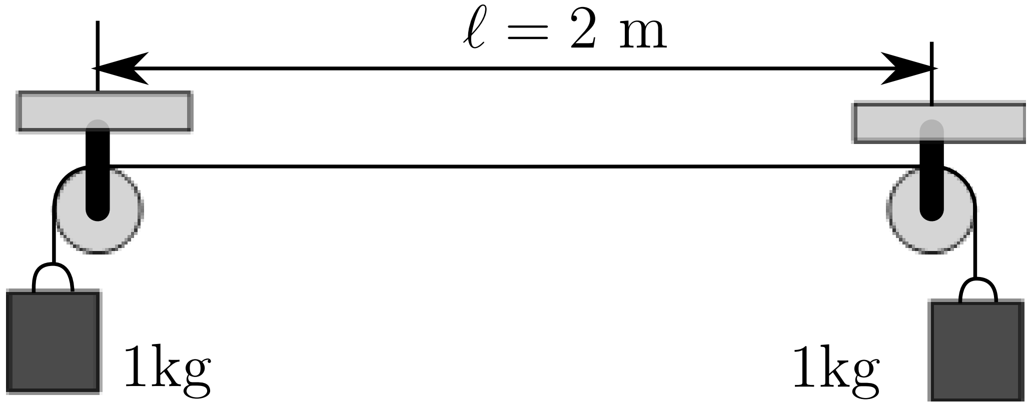
   For small amplitudes $\sin y = y - \frac{1}{3!} \cdot y^3 + \frac{1}{5!} \cdot y^5 - \frac{1}{7!} \cdot y^7 + - \cdots \ldots \ldots$

c) Explain the physical meaning of the negative sign.(2P)

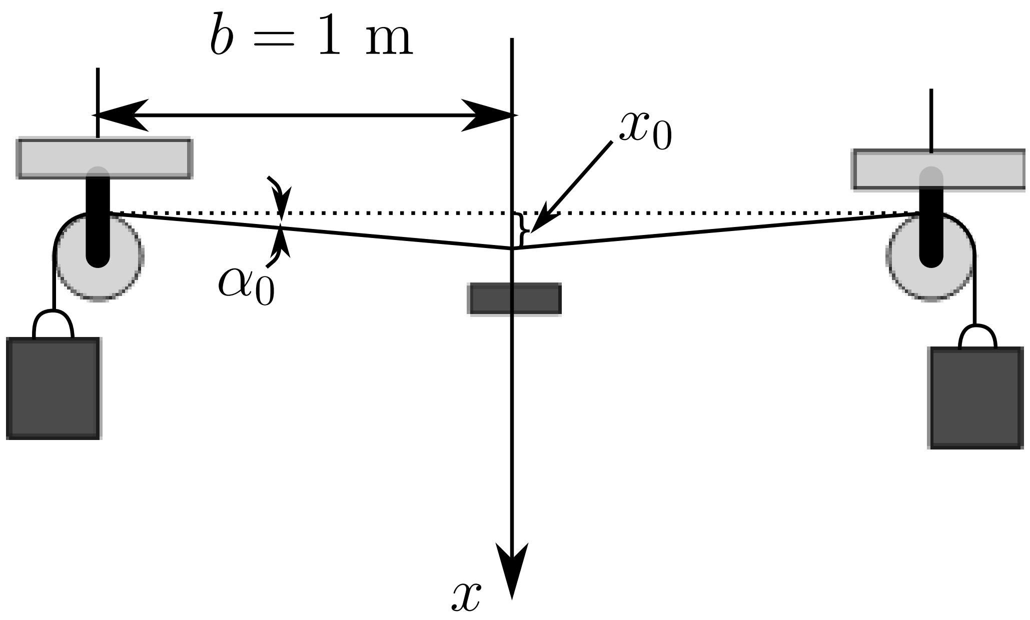
d) Calculate the period T of the oscillations. (4P)

e) We increase the masses M of the weights. The formula for the period does not change. Explain why the value of the period is decreasing. A mathematical explanation is not enough. (2P)

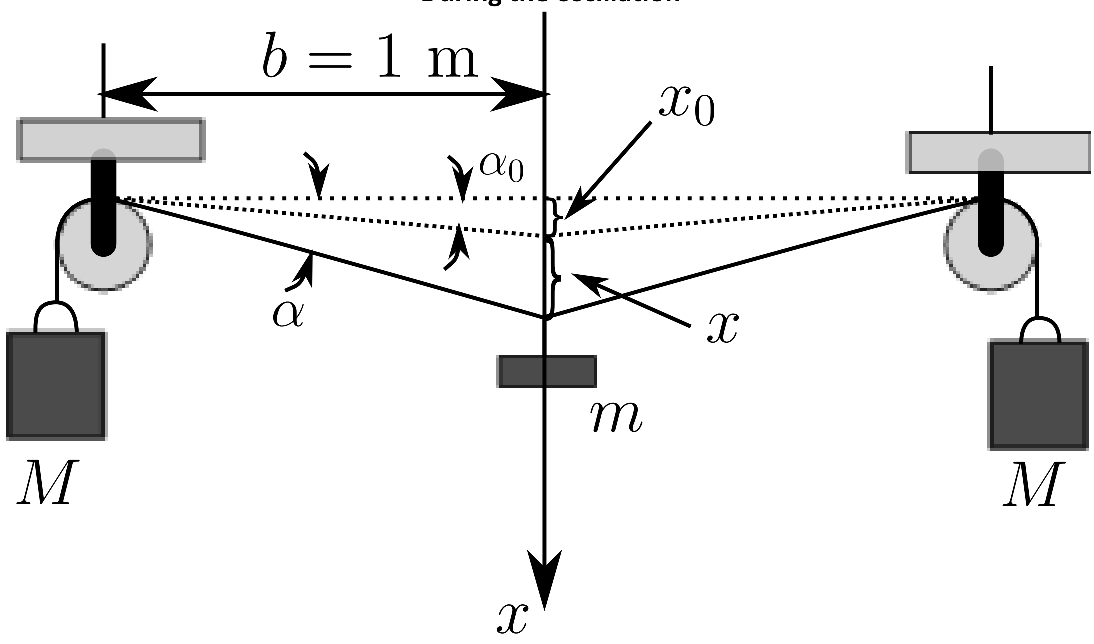
Answer:



Equilibrium position



During the oscillation



Question 3: Movement of an electron in a magnetic field

Electrons of speed v_0 enter a magnetic field of intensity B making an angle α <90 ° with velocity.

a) Show that these electrons describe a helical trajectory. Specify the characteristics of the helical axis, pitch and radius. (10P)

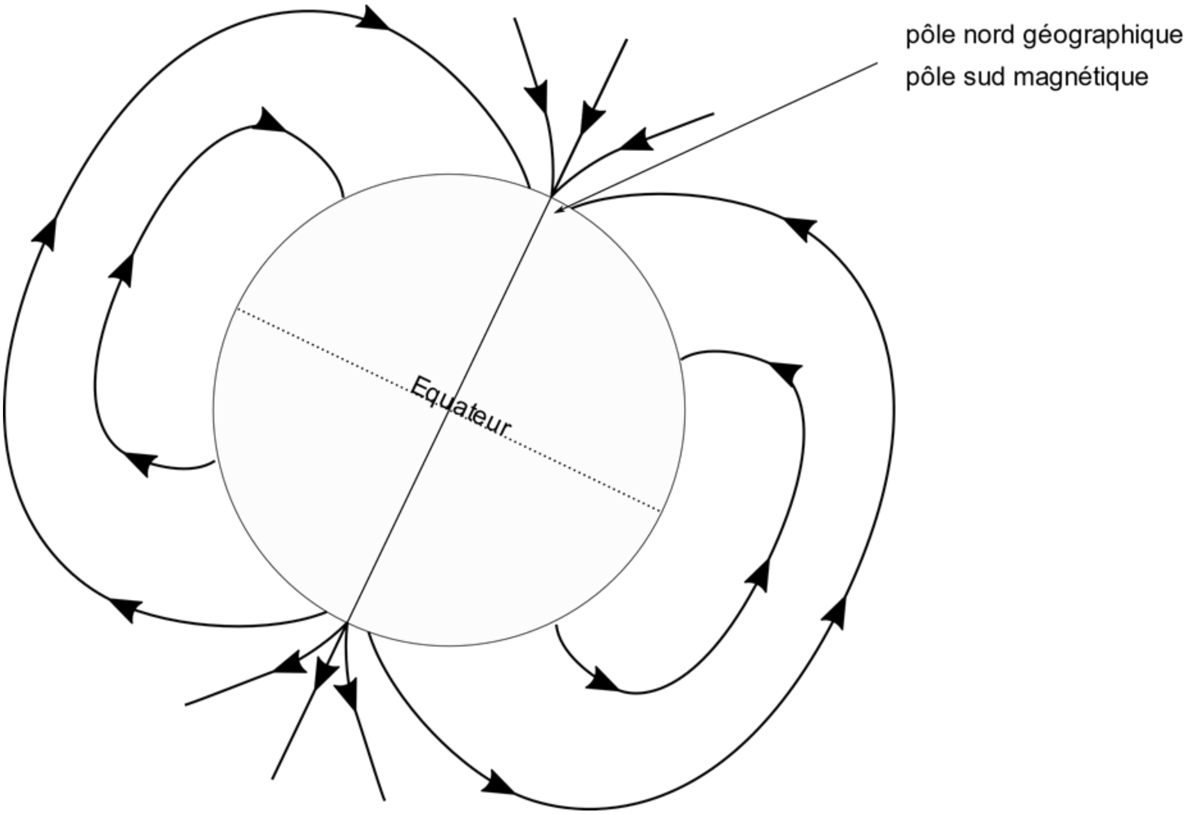
Information: The pitch of a helix is the displacement parallel to the axis for one complete revolution.

b) The solar wind is composed among other things, of a flow of electrons with a speed of 400 km / s. When entering the Earth's magnetic field of intensity $B = 5 \cdot 10^{-5}$ T, they follow circular or helical trajectories of radius r.

1. Can electrons touch the ground at the equator, and/or at the poles? Explain. (5P)

2. Calculate the radius r for the case where the angle between the field and the speed is 50 °. (5P)

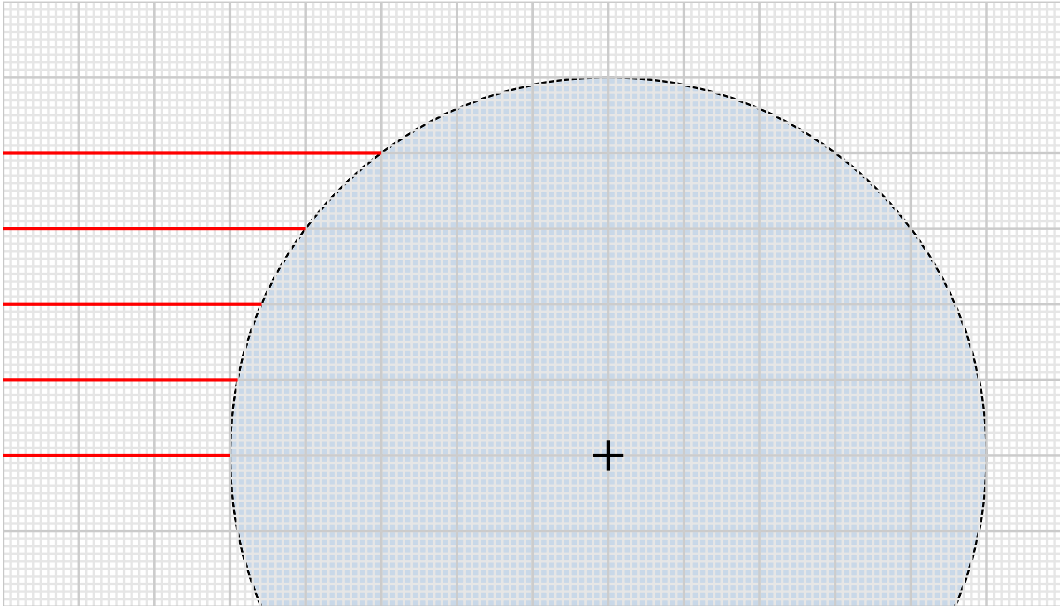
Diagram of the Earth's magnetic field:



Answer:

Question 3: Movement of an electron in a magnetic field Number:____

Question 4: Optics



Light rays are refracted on a spherical diamond with refractive index $n_2 = 2.5$. The refractive index of the air is $n_1 = 1$.

1. The sphere has a radius of R = 5 cm. For the rays of light that are horizontally spaced y cm from the optical axis (for y = 1,2,3,4 cm). Determine the angle of refraction, and draw the path of the refracted light rays on the above drawing. (8P)

2. Now consider the limit $y \ll R$. Show that in this case, all the rays meet at a focal point. Determine the focal length as a function of R (the focal length is defined as the horizontal distance from the front edge of the lens to the focal point). (8P)

3. Describe qualitatively (without calculation) where the focal point would be if it were a glass ball with $n_2 = 1.5$. (4P)

Answer:

Number:_____

Number:____

Number:_____