LËTZEBUERGER PHYSIKSOLYMPIAD
2025

Semi-final (EN)

11.02.2025

Instructions:

- Write your full name and school on each sheet.
- Clearly indicate which sub-/question you are answering.
- Start a new question on a new sheet of paper.
- Explain your reasoning and indicate intermediary calculations.
- Number your pages.

Formulae

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 laws

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

$pV = nRT = Nk_B T$

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

Oscillations and waves

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

$c = f\lambda$

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

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

Electricity

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

$F = k \cdot \frac{|q_1 q_2|}{r^2}$

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

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

$V = RI$

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

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

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

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

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

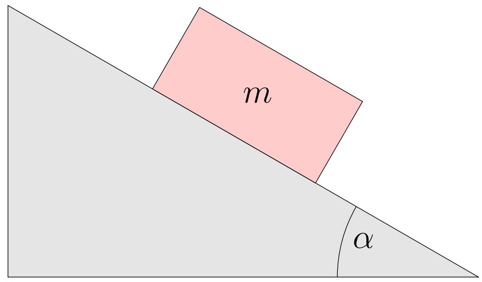
$n_1 \sin\alpha_1 = n_2 \sin\alpha_2$

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

Question 1: Mechanics (20 marks)

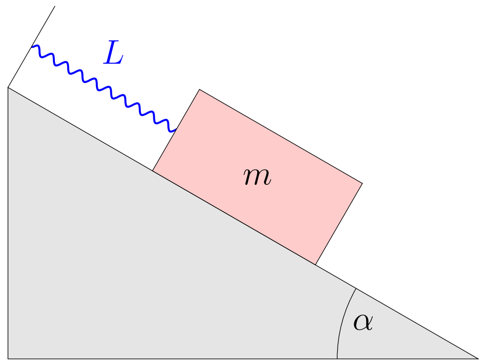
We consider a block of mass $m = 2\ \mathrm{kg}$, which is placed on a frictionless inclined plane that makes an angle of $\alpha = 30°$ with the horizontal axis. The block is attached to a spring with a spring constant k, so the restoring force is $F_{\text{spring}} = kL$, where L is the length of the spring. The other end of the spring is fixed at the top of the incline. Assume that gravitational acceleration $g = 9.8\ \mathrm{m/s^2}$ acts on the block.

For the part 1 and 2, we ignore the presence of the spring.



1) Calculate the gravitational force F_G acting on the block as well as the force component F parallel to the inclined plane. (4)
2) Determine the acceleration a of the block as it slides down the frictionless inclined plane. Make a drawing showing the directions of the forces $\vec{F}_G$ and $\vec{F}$, and the acceleration $\vec{a}$. (4)

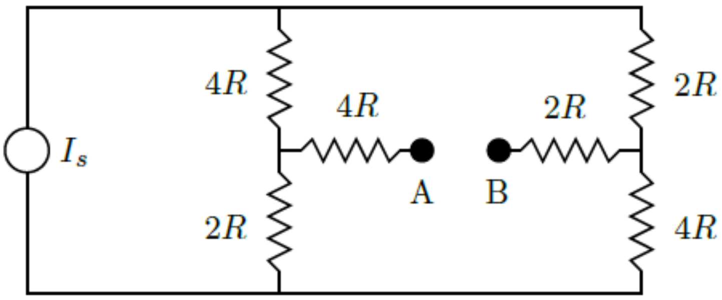
Now, we consider the effect of the spring.



3) Assume that the block is released at the top of the incline ($L = 0$), starts to slide, and stretches the spring to a length $L = 0.1\ \mathrm{m}$ when it comes to rest. Use this to calculate the spring constant k and the potential energy stored in the spring. (6)
4) Assuming the block is now on a rough inclined plane with a friction coefficient $\mu = 0.2$, calculate the distance L_2 the block slides before coming to rest when released from the same initial position. (6)

Question 2: Constant current source (20 marks)

Consider the circuit shown below. I_s is a **constant current** source, meaning that no matter what device is connected between points A and B, the current provided by the constant current source is the same.



1) An ideal voltmeter is connected between A and B.

   Knowing that an ideal voltmeter has infinite resistance

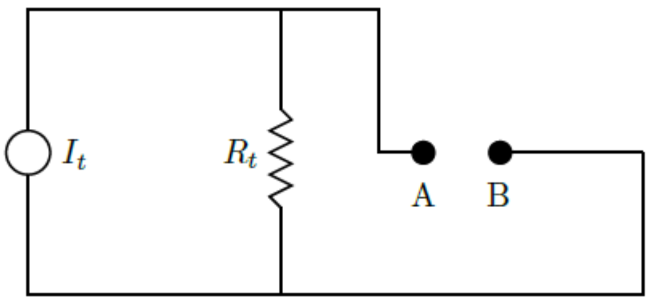
   a) Determine the voltage reading in terms of any or all of R and I_s and **explain your reasoning**. (5)

   b) Explain the meaning of the sign in the formula found under a). (1)

2) An ideal ammeter is connected between A and B instead of the voltmeter.

   Knowing that an ideal ammeter has zero resistance, determine the current in terms of any or all of R and I_s and **explain your reasoning**. (8)

3) It is possible to replace the above circuit with a new circuit as follows:



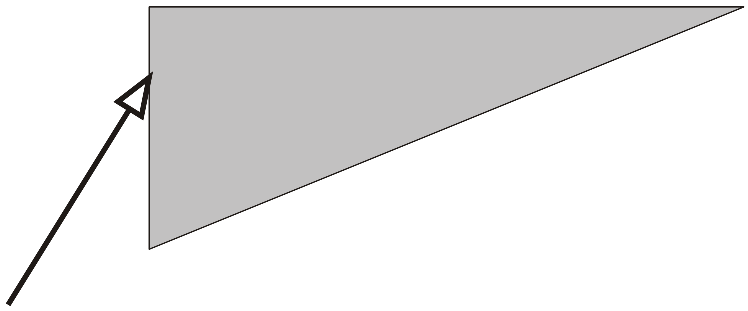
   From the point of view of any passive resistance that is connected between A and B the circuits are identical. You don't need to prove this statement (Norton's theorem).

   a) Explain what is meant by a passive resistance. (1)

   b) Find I_t and R_t in terms of any or all of R and I_s and **explain your reasoning**. (5)

Question 3: Path of light through a prism (20 marks)

A prism surrounded by air consists of a triangular transparent body ($n = 1.3$), see figure. Let's assume that the angle at the apex is $90°$ and that the incident ray forms an angle of $\alpha = 60°$ with respect to the normal of the surface.

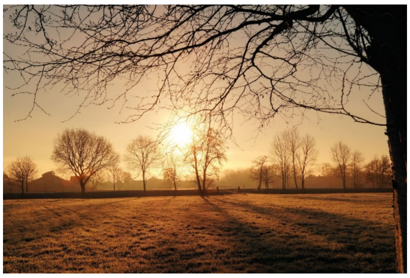


The relationship between the incident and refracted angles is (Snell's law):

$$\sin \alpha_1 = n \ \sin \alpha_2$$

1) Trace the path of light through the prism qualitatively. (2)
2) What is the angle with respect to the surface normal after the ray has been refracted? (3)
3) What is the distance travelled by the ray in the prism when the incident ray strikes the prism at a distance of 5 mm from its apex with a right angle? (4)
4) How long takes the light to pass through the prism? (2)
5) When the light reaches the other surface, what angle does it form with the normal of that surface? (2)
6) What is the exit angle (in air) of the light relative to the normal of the second surface? (3)
7) What is the minimum incident angle $\alpha_{\min}$ at which light can exit the prism through the second surface (at a smaller angle, it would be completely reflected)? (4)

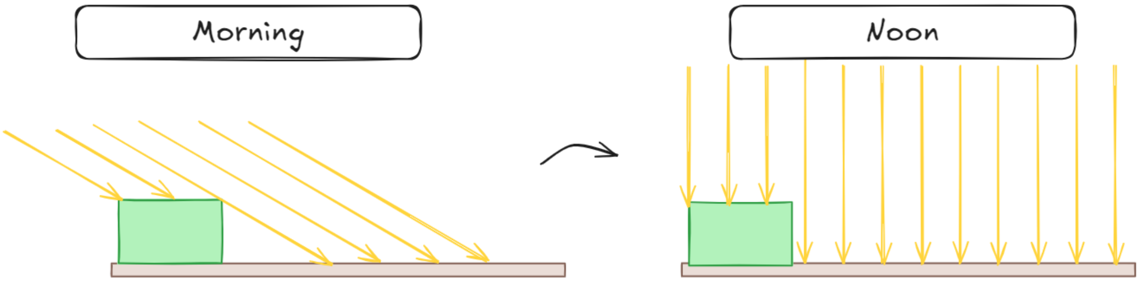
Question 4: Calorimetry (20 marks)



On a very cold winter's day, a layer of ice has formed on the grass. When the sun rises, surfaces exposed to the sun begin to melt, while surfaces in the shade remain frozen. This creates a boundary between the 2 regions. The sunny region includes a frozen region.

1) Explain this observation briefly. (2)
2) The initial temperature of the ice is assumed to be $-5\ °\text{C}$. Calculate the energy required to melt $1\ \text{kg}$ completely. (3)
   ($c_{\text{ice}} = 2.06\ \text{kJ/(kg K)};\ c_{\text{water}} = 4.18\ \text{kJ/(kg K)};\ L_{\text{f}} = 334\ \text{kJ/kg}$)
3) At midday, it is assumed that the Sun provides a light output of $500\ \ \text{W/m}^2$ and that the ice on $1\ \text{m}^2$ melts in 1 minute. Determine the mass of the ice present. (3)
4) Knowing that the thickness of this layer of ice is $0.05\ \text{mm}$, calculate the effective surface area of the grass. (1)

We now study how the shadow and the ice-covered area change over the course of the morning. We use a simplified model where the sun passes exactly over the zenith of the location under consideration at midday. A forest, approximated by an opaque rectangular block of height $h = 20\ \text{m}$, casts the shadow onto a flat horizontal field. The point M marks the boundary between the shadow and the illuminated area.



5) Express the speed of the point M as a function of $h, t, \omega = \omega_{\text{Sun}}$ where $t = 0$ corresponds to sunrise (at 6.00 am). (6)
6) Using the data from the exercise above, estimate the width of the sunny but icy strip at 9.00 am. Bear in mind that the radiation power changes with the angle of incidence. (5)