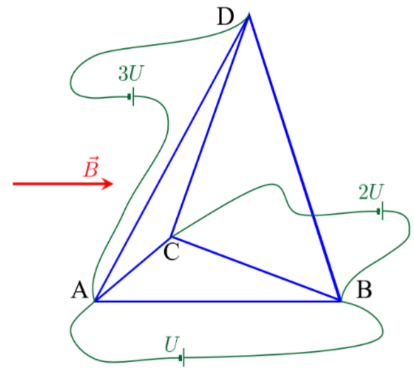
All-Ukrainian Student Olympiad in Physics, Lviv, 2025
Theoretical round, 11th grade

March 2025

1 Electromagnetic stereometry



A regular tetrahedron ABCD with edge length l is made of uniform wire so that the resistance of each edge is R. Between points A and B an ideal source with voltage U is connected, between points B and C another source with a voltage of 2U, and between points A and D a third source with a voltage of 3U. The tetrahedron is located in a homogeneous magnetic field with induction vector B directed along the edge AB.

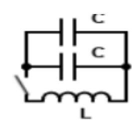
1.1 Find resistance between two vertices

1.2 Find current in each edge

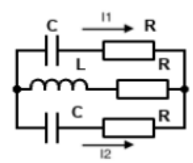
1.3 Prove that force acting on a tetrahedron equals to the Amper force acting on a straight conductor connecting the points connected to a source of voltage (If we only consider one U at a time)

1.4 Find force acting on a tetrahedron from the side of homogeneous magnetic field. You may use the result of 1.3 even if you didn‘t do it

2 Schematic madness

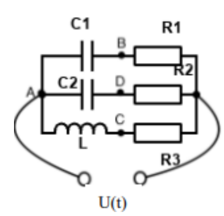


The oscillating circuit shown in the figure consists of two capacitors C= 1000 µF, an inductor L = 0.1 H, and a key. Initially, the key was open, and the charge on each capacitor was equal to q.



2.1 Find the maximum current through the coil Imax after the key is closed.

Let‘s change the circuit. Connect a resistor to each element of the oscillating circuit with a resistance of R = 10 Ohm (see figure). At a certain point in time, the following conditions are met: $\frac{dI_L}{dt} = 0$, $I_1 = 10A, I_2 = 12A$.



2.2 Find the maximum amount of heat Q that can be released in a system from this point in time.

Let’s further modify the circuit. Replace the resistors with a resistance of R = 10 Ohm with resistors of different resistance and connect the circuit to an alternating voltage source with known amplitude value U_0 and cyclic frequency ω (see the third figure). It is known that the parameters of the system are related to each other by the relation $\frac{1}{C_1 \omega R_1} = \frac{\omega L}{R_3} = \sqrt{3}$.

2.3 Express the amplitude values of U_{CA} and U_{BA} through U_0 after the oscillations are established

3 Alien disk

The alien space station, which has the shape of a thin flat disk, is preparing to travel through some galaxy.

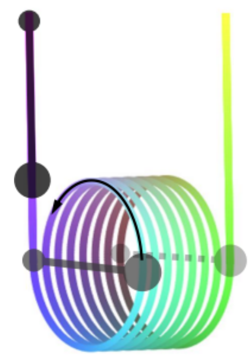
3.1 Artificial gravitation

Having large reserves of energy, the aliens solved the problem of the lack of gravity, accelerating their station so that it would experience an acceleration of $a = 15m/s^2$. Assuming that the station starts near the center of the galaxy, find the speed it will gain relative to this center of the galaxy when according to the galactic clock $t = 2 \times 10^7 s$ will pass. The speed of light in a vacuum is $c = 3 \times 10^8 m/s$

3.2 Collision

Immediately before the launch, when the station was not yet spinning, the aliens notice an asteroid of mass m flying in their direction. Assuming that the asteroid impact was completely inelastic, and immediately before the collision the asteroid was at a distance b from the center of the station and had a small velocity v, directed perpendicular to the plane of its disk, find in which places on the station did not felt the acceleration from the impact. The mass of the station is M. The moment of inertia of a homogeneous disk about the axis passing through the center of mass and lying in the plane of the disk is equal to $MR^2/4$

4 Problem with intranslatable name



The figure shows a rigid wire in the form of a fragment of a helical line with its vertical ends straightened. Two balls are attached to the wire, hinged by a light rod of the longest possible length, which allows this “dumbbell” to move along the helical line. In the initial position, the lower ball (the larger one in the figure) was held at the level of the upper parts of the wire turns. The balls are released. The forces of friction, air resistance, and the size of the balls are neglected. The acceleration of free fall $g = 9.8m/s^2$, radius of the helical line $R = 20cm$. The figure is schematic, but the number of turns on it is accurate.

4.1 Part 1

Find the time of movement of this “dumbbell” along the arcs of the helical line, i.e. from one extreme horizontal position of the rod to the other (see Fig. Figure). Keep in mind that the masses of the balls are the same, and the distance between the turns of the spiral line is much smaller than its radius.

Next, consider the case where the larger ball has three times the mass of the smaller one, and the distance between the turns is $h = 18cm$. Remember to take into account the corresponding change in the length of the “dumbbell” due to this distance.

4.2 Part 2

To what maximum height will the larger ball rise after passing through a spiral line?
(Note from the translator: don‘t forget that the dumbell may not be completely vertical in the end)

4.3 Part 3

Due to the small frictional and drag forces, the motion of the balls gradually slows down. Determine the period of small oscillations of the balls over after a long period of time.
(Note from the translator: there are two possible positions where it will oscillate, one between two turns, one on the edge of a turn and a vertical line)

Note that the distance between the turns h = 18 cm is measured along the axis of symmetry of the helical line, and the radius R is measured in the perpendicular direction.

5 Day/Night

The space expedition reached a star system consisting of a central massive star (C), one planet (P) and its satellite (S). The radius of the planet is 6000 km, the radius of the satellite is 1000 km. The satellite moves in a circular orbit with a radius of 400000 km. The average density of the planet and the satellite is the same: 5000 kg/m3. The distance from the planet to the star is several hundred million kilometers. A day on the planet lasts 12 Earth hours, the axis of daily rotation forms a right angle with the plane A of the planet's orbit around the star.
The expedition measures the acceleration of free fall on the planet.
Gravitational constant $G = 6.67 * 10^{-11} Nm^2/kg^2$

5.1 Part 1

By what percent do the accelerations of free fall at the pole and at the equator differ due to the daily rotation of the planet?

5.2 Part 2

Estimate the percentage difference in free fall acceleration at different points of the equator due to the gravitational influence of the planet's satellite.

5.3 Part 3

A satellite is a sphere without an atmosphere, each small part of its surface absorbs 40% of the energy of the incident light in any wavelength range, and reflects the rest in all directions in such a way that all the illuminated parts of the satellite's "disk" look equally bright from a distance. Let the angle α be the angle between the directions "satellite-star" and "satellite-planet". The orbital plane of the satellite around the planet coincides with the plane A, do not take into account the possibility of eclipses. The expedition also observes changes in the illumination E of the planet's equator for a for a long time. Determine the relationship $\frac{E_{night}}{E_{day}}$ from . (E_{night}, E_{day} - illuminations at midnight and midday with the same). Draw a sketch of this relationship.