Physics Mock Test No. 1

IJSO MCQ mock test

This is an IJSO Physics mock test, designed to mimic the style, depth, and difficulty of physics questions found in the IJSO. Its aim is to help students strengthen their understanding of the physics concepts behind the IJSO and similar competitions.

The questions in this paper were made by the following members of our team (in alphabetical order):

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In solving the questions, you might need to use the following constants:

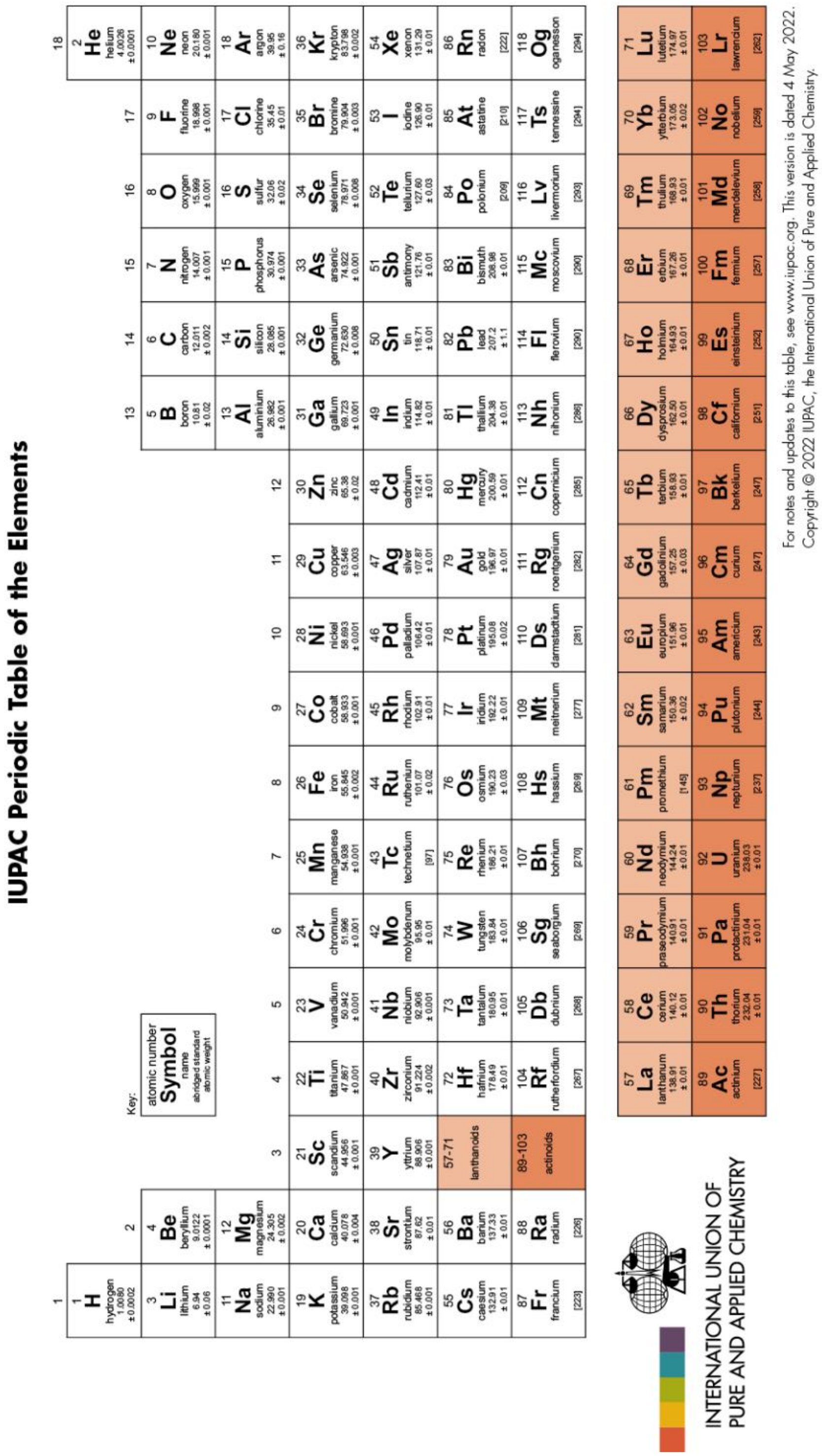
Constant	Notation	Value
Acceleration due to gravity	g	$9.8\ ms^{-2}$
Gravitational constant	G	$6.67 \cdot 10^{-11}\ m^3/\ kg \cdot s^2$
Planck's constant	h	$6.62 \cdot 10^{-34}\ J \cdot s$
Elementary charge	e	$1.6 \cdot 10^{-19}\ C$
Speed of light in vacuum	c	$3 \cdot 10^8\ ms^{-1}$
Density of water	ρ	$1000\ kg\ m^{-3}$
Stefan-Boltzmann constant	σ	$5.67 \cdot 10^{-8}\ \frac{W}{m^2K^4}$
Universal gas constant	R	$8.314\ J\ mol^{-1}\ K^{-1}$ $0.0821\ atm\ L\ mol^{-1}\ K^{-1}$
Avogadro's number	N_A	$6.022 \cdot 10^{23}\ mol^{-1}$
Faraday's constant	F	96 500 C/mol
Pi	π	3.14
Electrical permittivity of free space	ε_0	$8.85 \cdot 10^{-12}\ F \cdot m^{-1}$
Magnetic permeability of free space	μ_0	$4\pi \cdot 10^{-7}\ H/m$
Mass of Earth		$5.97 \cdot 10^{24}\ kg$
Mass of Moon		$7.35 \cdot 10^{22}\ kg$
Mass of Sun		$1.99 \cdot 10^{30}\ kg$
Radius of Earth		$6.4 \cdot 10^{6}\ km$
Radius of Moon		$1.7 \cdot 10^{6}\ km$
Radius of Sun		$6.96 \cdot 10^{8}\ km$
Specific heat capacity of water	c_w	$4200\ J/kg \cdot °C$
Average molar mass of air	M	28.9 g/mol

If any other value is provided in the problem, use the value provided, not the one in the table. You can also use the following conversion formulas:

$T\ (K) = t\ (°C) + 273$	$t\ (°F) = \frac{9}{5} t\ (°C) + 32$
$1bar = 1atm = 101\ 000Pa = 760mmHg$	$1u = 1Da = 1.66 \cdot 10^{-27}kg$
$1L = 10^{-3}\ m^3$	$1\ day = 24h$

If needed, you can use the periodic table given bellow:

(Use atomic masses rounded to two decimal places.)



Question 1 – Two objects colliding

An object with mass M and speed V approaches a block with mass m, at rest. Both objects are on the top of a cliff a height h above the ground. After the blocks collide, the object with mass m lands a horizontal distance d from the cliff edge. Assuming the objects collide inelastically, determine the ratio m/M.

A. $1-\frac{V}{d}\sqrt{\frac{2h}{g}}$

B. $\frac{V}{d}\sqrt{\frac{2h}{g}}-1$

C. $\frac{V}{d}\sqrt{\frac{2h}{g}}$

D. $\frac{2V}{d}\sqrt{\frac{2h}{g}}$

Problem proposed by Jailson Godeiro

Question 2 – Cylinder with a piston

Consider a horizontal cylinder, with cross section area S. One of the ends of a cylinder is a piston that can slide freely without friction. Initially, the piston is left free, such that the pressure of the gas inside the cylinder is equal to the atmospheric pressure, P_0. The distance from the fixed end of the cylinder to the piston is L_0.

After that, a force F starts pushing on the cylinder, compressing the gas, such that the cylinder moves with constant velocity v. Assume that the cylinder is a perfect thermal conductor and the temperature of the system remains constant throughout this process.

What is the equation that shows how F varies with time?

A. $F(t) = \frac{vt}{L_0 - vt} P_0 S$

B. $F(t) = \frac{L_0}{L_0 - vt} P_0 S$

C. $F(t) = \frac{L_0 - vt}{L_0} P_0 S$

D. $F(t) = \frac{L_0 - vt}{vt} P_0 S$

Problem proposed by Alex Jicu

Question 3 – New unit system

Consider a new system of units where the speed of light c and the gravitational constant G are numerically equal to 1 and the unit of measurement for mass is still the kilogram, what should be the numerical value of Planck's constant h on this new system?

A. 2.98×10^{-15}
B. 3.13×10^{-15}
C. 6.62×10^{-16}
D. 1.92×10^{-16}

Problem proposed by Jailson Godeiro

Question 4 – Heating water

100 ml of water was inside a calorimeter. A heater with unknown, yet constant power supplied heat for 5 minutes. The temperature of the calorimeter and the water rose by 5 degrees. Later, the same heater supplied heat for 50 ml of water and the calorimeter. It took the heater 3 minutes to increase the temperature by 5 degrees. Find the specific heat capacity of the calorimeter. Take $c_{water} = 4200\ J/\ kg \cdot {}^{\circ}C$.

A. $90\ J/{}^{\circ}C$
B. $105\ J/{}^{\circ}C$
C. $210\ J/{}^{\circ}C$
D. $2100\ J/{}^{\circ}C$

Problem proposed by Thenura Wickramaratna

Question 5 – Point charges

Three point charges are placed at the vertices of an equilateral triangle of side length L = 1m. The electric charges are q1 = 10 nC, q2 = - 4 nC and q3 = - 2 nC. Calculate the total potential electrostatic energy stored in the system.

A. -468 nJ
B. +612 nJ
C. -612 nJ
D. +468 nJ

Problem proposed by Alex Jicu

Question 6 – Light in a dome

A transparent hemispherical dome of radius 10 cm is placed flat side down on a table. A small laser pointer is placed at a point P, 10 cm above the flat surface and 10 cm horizontally from the central axis (i.e., at a 45° angle to the center). The dome is made of a material with refractive index 1.60, and the surrounding medium is air (n = 1.00).

The laser beam enters the dome without any refraction (it strikes the curved surface perpendicularly), but after reflecting internally off the flat surface, it hits the curved surface again from inside.

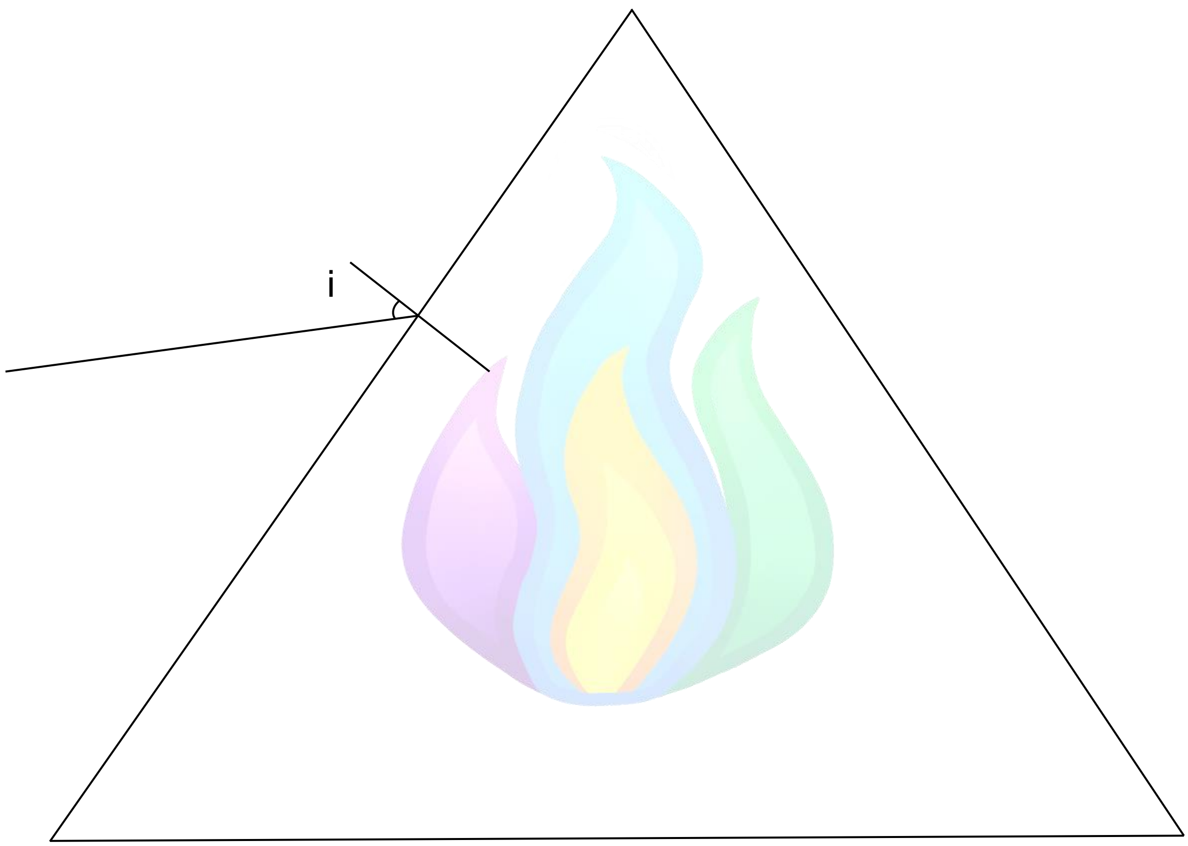
What will happen to the beam at this second point of incidence?

A. It will refract out of the dome at a steeper angle than it entered.
B. It will reflect again due to total internal reflection.
C. It will refract out of the dome at a shallower angle than it entered.
D. It will leave the dome without refracting.

Problem proposed by Thenura Wickramaratna

Question 7 – Light in a prism

An equilateral triangular glass prism (refractive index n = 1.50) is placed in air. A narrow laser beam enters one of the prism's slanted faces with an incidence angle of 45° (measured from the normal). After refraction into the prism, the beam strikes the base and reflects from the mirror-like surface. It then emerges from the other slanted face, opposite to the one through which it originally entered.

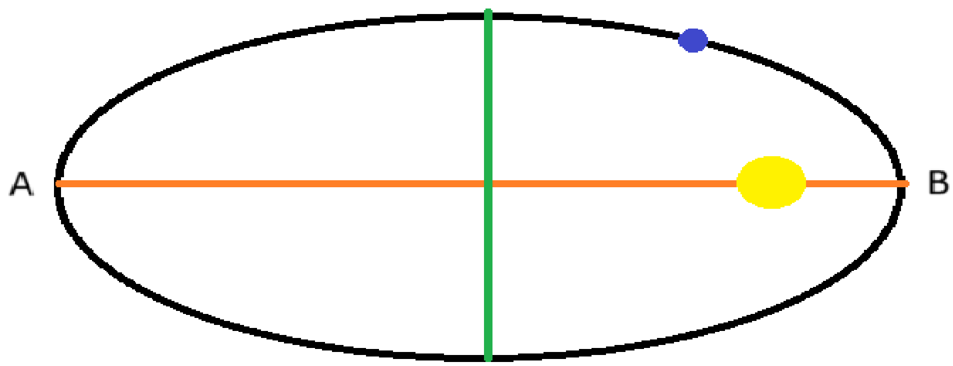


A. The beam will emerge closer to the base of the prism than the original incident beam.
B. The beam will emerge at a greater angle to the normal than the original incidence.
C. The beam will be totally internally reflected again at the second face.
D. The beam will leave at a 45° angle.

Problem proposed by Thenura Wickramaratna

Question 8 – Star-planet System

About this orbit of a planet around its star, assuming it occurs in the counterclockwise direction, what is the sum of the numbers associated with correct statements?



16. The planet's kinetic energy is decreasing

8. The orbit is hyperbolic

4. The star and planet can have similar masses

2. In A, the planet's potential energy is bigger than B

1. If the distance between the planet and the star gets 3 times bigger, the strength of the gravitational interaction between them gets 9 times smaller.

A. 12
B. 17
C. 19
D. 21

Problem proposed by Jailson Godeiro

Question 9 – Simple circuit

A battery of emf 12 V and internal resistance 1 Ω is connected to a circuit with two resistors, $R_1 = 5\ \Omega$ and $R_2 = 10\ \Omega$ a, connected in parallel. A switch S is connected so that when closed, it bypasses R_2.

What is the percentage change in power dissipated in the external circuit when the switch is closed?

A. Increases by 7.7%
B. Increases by 25%
C. Decreases by 7.7%
D. Decreases by 25%

Problem proposed by Thenura Wickramaratna

Question 10 – Liquid in a glass

A liquid with a coefficient of volume expansion γ is placed in a cylindrical glass container, what should be the value of γ so that the height of the liquid remains unchanged after the system is heated?

Coefficient of Linear Expansion of glass: $9.0 \times 10^{-6}\ °\mathrm{C}^{-1}$

A. $4.5 \times 10^{-6}\ °\mathrm{C}^{-1}$
B. $9.0 \times 10^{-6}\ °\mathrm{C}^{-1}$
C. $1.8 \times 10^{-5}\ °\mathrm{C}^{-1}$
D. $2.7 \times 10^{-5}\ °\mathrm{C}^{-1}$

Problem proposed by Jailson Godeiro

Question 11 – Large ball and small balls

A very large number of balls of mass m are placed in a straight line. A large ball of mass M = 2025m comes towards the line of small balls, with velocity u (the same direction as the line of balls m). The ball M collides with each ball m elastically (and the small ball m is deflected such that it won't hit other small balls, but the collision can be considered unidimensional). After how many collisions will the velocity of the ball be reduced to 2.025% of u?

A. 1429
B. 2025
C. 3949
D. 7899

Problem proposed by Alex Jicu

Question 12 – Air resistance part 1

A rocket of mass M ejects fuel at a rate λ with speed u. It moves upward from a viscous fluid that applies a drag $F_D = kv^2$. Find the terminal velocity v_t of the rocket.

A. $v_t = \sqrt{\frac{u\lambda}{k}}$
B. $v_t = \frac{u\lambda}{k}$
C. $v_t = \sqrt{\frac{k}{u\lambda}}$
D. $v_t = \frac{k}{u\lambda}$

Problem proposed by Thenura Wickramaratna

Question 13 – Air resistance part 2

A small sphere (mass m, radius r) is dropped in air (from rest) where the drag force $F_D = kv$ (linear drag) where k is an arbitrary constant. Then the experiment is repeated in a different fluid where the drag force is $F_D = cv^2$ (quadratic drag) where c is an arbitrary constant. If the sphere's terminal velocities in the two fluids are equal to v_t, find the ratio of initial accelerations $\frac{a_{0,lin}}{a_{0,quad}}$

A. 1
B. $\frac{1}{g}$
C. $\frac{2v_t}{g}$
D. Not enough information given

Problem proposed by Thenura Wickramaratna

Question 14 – Stefan-Boltzmann law

The Stefan-Boltzmann law is used to calculate the amount of energy per unit time per unit area radiated by a black body. Its equation is $P = \sigma A T^4$, where T is the temperature (in Kelvin), A is the surface area of the body, σ is the Stefan-Boltzmann constant and P is the power (the amount of energy radiated per unit time).

The Stefan-Boltzmann constant can be calculated with the formula $\frac{2\pi^\alpha}{15} k^\beta c^\gamma h^\delta$, where $k = 1.38 \times 10^{-23}\ \mathrm{J/K}$ is called the Boltzmann constant, $c = 3 \times 10^8\ \mathrm{m/s}$ is the speed of light in vacuum, $h = 6.62 \times 10^{-34}$ Js is called the Planck constant and α, β, γ and δ are integer exponents.

The numerical value of the Stefan Boltzmann constant expressed in the SI unit is 5.67×10^{-8}.

What is the sum of α, β, γ and δ?

A. 0
B. 4
C. 10
D. 14

Problem proposed by Alex Jicu

Question 15 – Circular coil

A circular coil, with radius $R = 10$ cm, is initially on the xy plane. The coil starts rotating around the y axis with constant angular speed $\omega = 5 \times 10^{-2}\ \mathrm{rad/s}$. If the coil is in a region of a constant magnetic field $B = 2000$ T on the z axis, what is the average induced electromotive force on the coil between the beginning of the rotation and 10 seconds after it starts rotating.

Useful formulas:

$$|\varepsilon| = \frac{\Delta\phi}{\Delta t}$$

Where ε is the induced electromotive force, and ϕ is the magnetic flux, defined as

$$\phi = B \cdot A \cdot \cos\theta$$

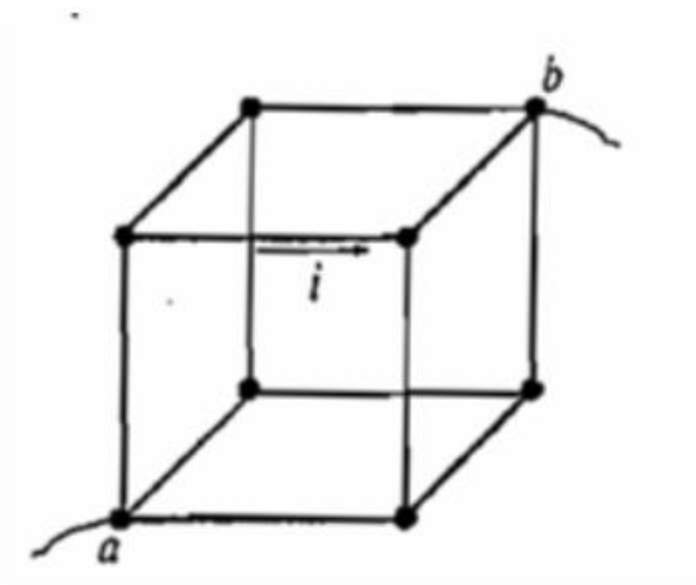
Where A is the area the magnetic field passes through (In this case it's the area of the coil) and θ is the angle between the magnetic field and the vector perpendicular to the surface.

A. 0.36 V
B. 0.62 V
C. 0.77 V
D. 0.98 V

Problem proposed by Jailson Godeiro

Question 16 – Resistance of a cube

The resistance of each edge of the cube is r, and a current of magnitude i flows through the shown edge (see figure).



What is the voltage (potential difference) between points a and b?

A. $4\,i \times r$
B. $5\,i \times r$
C. $7\,i \times r$
D. $12\,i \times r$

Problem proposed by Luka Smiljanic

Question 17 – Waves in a copper wire

A copper wire, with undeformed length $L_0 = 10\text{m}$, elastic constant $K = 314$ N/m and cross section radius r = 0.1mm has one end tied to a fixed point and the other tied to a point that can move periodically in a horizontal plane, between two fixed points A and B, creating a wave in the wire. The stress due to the oscillations makes the length of the wire to be equal to L = 10.1m.

It is known that the speed of a longitudinal wave is $v = \sqrt{\frac{E}{\rho}}$, where E and ρ are the Young's modulus and density of the medium through which the wave propagates, while the speed of a transverse wave is $v = \sqrt{\frac{T}{\mu}}$, where T is the tension in the object oscillating and μ is the mass per unit length.

The density of copper is known to be $\rho_{Cu} = 8900\ \text{kg/m}^3$.

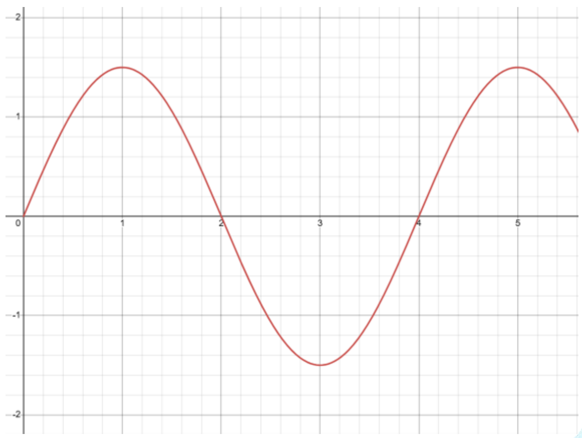
If the movable end of the wire takes 0.05 s to move from point A to point B, what is the wavelength of the wave that appears in the wire (ignore reflection at the fixed end)?

A. 16.75 m
B. 33.50 m
C. 167.6 m
D. 335.2 m

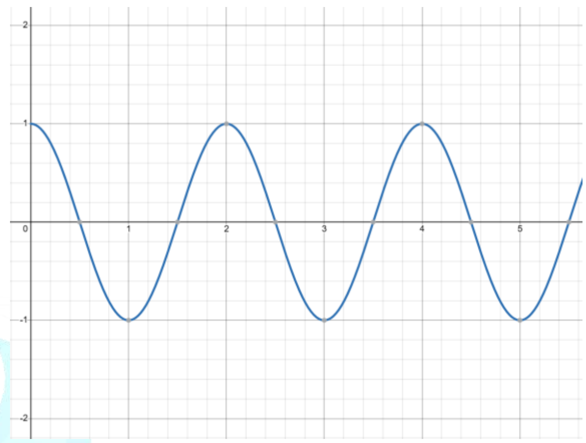
Problem proposed by Alex Jicu

Question 18 – Types of waves

Consider two mechanical waves, propagating through space. The two following graphs give the elongation in terms of the distance from the source of the waves:



Wave 1



Wave 2

Considering both waves propagate with speed c = 100m/s, which of the following is true?

A. The wavelength of wave 1 is equal to 2m
B. These two waves can present both constructive and destructive interference
C. The frequency of wave 2 is 100 Hz
D. The amplitude of wave 2 is 2m

Problem proposed by Alex Jicu

Question 19 – Block in a subway car

A 12 m long subway car starts from rest and accelerates forward at $a=4.0\ \mathrm{ms}^2$ for $t_1 = 2\mathrm{s}$ after which the car starts moving at a constant velocity. A small block placed on the floor at the **front** of the car slides toward the **back** due to kinetic friction. Assume static friction is negligible and take $g = 10\ \mathrm{ms}^2$. The block just reaches the halfway point exactly at the end of the 2 seconds. Find how much more time it will take for the block to reach the back of the train.

A. 0.950 s
B. 1.101 s
C. 1.306 s
D. 2.304 s

Problem proposed by Thenura Wickramaratna

Question 20 – Photoelectric effect

The photoelectric effect was discovered by Heinrich Hertz in 1887 while he was studying the properties of electromagnetic waves. Later, in 1905, Albert Einstein provided the theoretical explanation, which earned him the Nobel Prize in Physics in 1921, using the photoelectric effect as experimental proof for the wave-particle duality. What does the photoelectric effect refer to?

A. The conversion between light particles (photons) and light waves, under the influence of electric discharge
B. The emission of light by circuits with high current intensities, such as a common light bulb
C. The amplification (rise in intensity) of light due to interaction with an electric field
D. The generation of a stable current in a circuit, due to the interaction of a circuit element with light

Problem proposed by Alex Jicu

Question 21 – Fish in the river

A fisherman is nearby a river and spots a fish that seems to be 2 meters deep, however, due to light refraction, the depth of the fish is not the same as the apparent depth perceived by the fisherman, if the index of refraction of water is 4/3, what is the actual depth of the fish?

A. 1.50 m
B. 2.50 m
C. 2.67 m
D. 3.00 m

Problem proposed by Jailson Godeiro

Question 22 – Unusual universe

Since childhood, science enthusiasts have all learned one fun fact about magnets - you can't have a magnet with only one pole (a magnetic monopole) - every magnet comes with a north pole and a south pole. That also means there is no such thing as a magnetic charge - the net magnetic charge of all objects is zero.

Let's forget this fact and suppose we live in a Universe where magnetic monopoles exist. We'll use the notation q_m for magnetic charges and q_e for electric charges to avoid confusion.

Very similarly to the electrostatic force, the force between two magnetic monopoles is given by $F_m = \frac{\mu_0}{4\pi}\frac{q_{m1}q_{m2}}{r^2}$.

Consider two point-like objects, in vacuum, at a distance $r = 1\ \mu m$, each with both electric and magnetic charges. The charges of the first object are q_{e1} =10 nC and $q_{m1} = 3\ Tm^2$, and the electric charge of the second object is q_{e2} = -5 nC. The magnetic charge of the second object is chosen such that the system is in equilibrium.

Using the similarity between electric and magnetic field, we can also define a magnetic potential for magnetic charges, where the expression takes a very similar form as the electrostatic potential

What is the value of the magnetic potential at the midpoint between the two particles?

A. $0.45\ T \cdot m$
B. $0.90\ T \cdot m$
C. $2.9 \times 10^{11}\ T \cdot m$
D. $5.7 \times 10^{11}\ T \cdot m$

Problem proposed by Alex Jicu

Question 23 – Hollow sphere

A solid sphere (radius 5.00 cm) is made of a material of density 6.00 g/cm^3 but has a tiny central cavity (vacuum). When placed in water, it **just** floats with a small cap above the surface. What is the radius of the cavity?

A. 2.59 cm
B. 3.08 cm
C. 3.84 cm
D. 4.71 cm

Problem proposed by Thenura Wickramaratna

Question 24 – Water tank with a hole

A water tank, filled with water up to a height of H = 1m has a circular hole at the bottom, of diameter d = 5cm.

On the hole, a small massless disk with D = 6 cm is put such that it covers it entirely. A rope has one end tied to the middle of the disk and one end outside of the water. To drain the tank, one simply has to pull the rope until the disk is lifted, and the entire amount of water will get drained through the hole.

What is the minimum force required to do this operation?

A. 27.70 N
B. 114.1 N
C. 310.5 N
D. 456.4 N

Problem proposed by Alex Jicu

Question 25 – Projectile motion

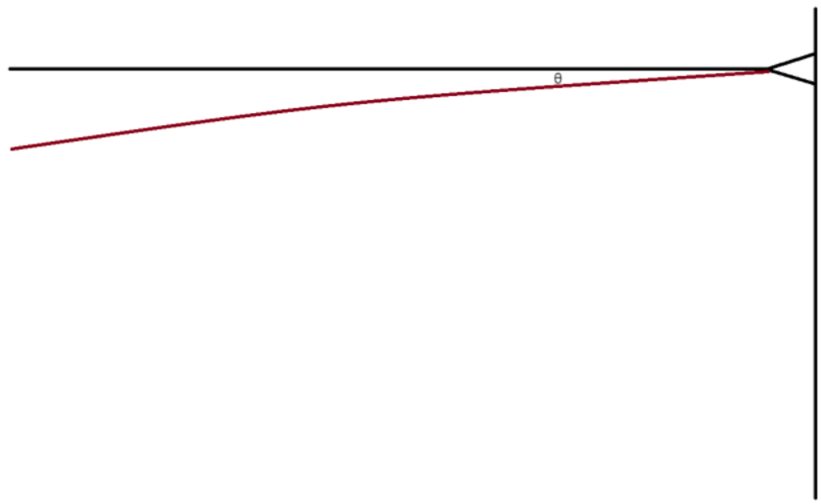
A projectile is launched from the ground with a horizontal inclination angle $\theta = 11°$ and speed $v = 832\ \mathrm{m/s}$. What distance should it initially be to the bottom of a $39\ \mathrm{m}$ tall building so that the projectile strikes a target at its top before reaching maximum height.

A. 92 m
B. 122 m
C. 202 m
D. 272 m

Problem proposed by Jailson Godeiro

Question 26 – Homogenous rod

A 10-meter-long homogenous rod with m = 1kg is suspended onto a vertical wall via a fixed articulation (see the figure).



In the figure above, the brown line is the rod, and the black line is just a horizontal line for reference. Even though in reality the rod is slightly curved, we can consider a simple model in which it is a perfectly straight line. The deflection angle is $\theta = 10^\circ$.

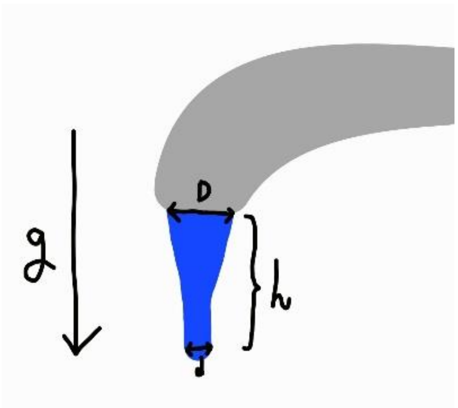
The articulation opposes the deflection of the rod, generating a clockwise torque given by $\tau = \kappa\theta$, where θ is the deflection angle in radians.

In the system above, what is the value of κ?

A. 276.5 Nm
B. 280.7 Nm
C. 553.0 Nm
D. 561.5 Nm

Problem proposed by Alex Jicu

Question 27 – Water hose



4.00 L of water is flowing out from a faucet every minute, through its spout that is shaped like a circle and has the diameter of D = 2.00cm. Calculate the diameter of the water's cross-section at h = 15.0cm.

A. 0.305 cm
B. 0.410 cm
C. 0.701 cm
D. 1.401 cm

Problem proposed by Doyoon Kim

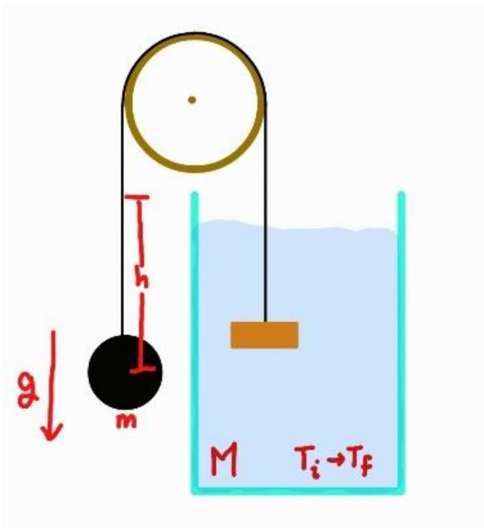
Question 28 – Different densities

A large vessel is divided into two equal compartments by a removable wall. Each of the two compartments is filled with 100 mL of water and oil respectively. The height of the two liquids is 10 cm. At some moment in time, the wall is removed, and the two liquids change their positions. After enough time, the system settles into a static equilibrium position. What is the total amount of mechanical energy that was lost by the system after the wall was removed? The two densities are $\rho_w = 1000\ \mathrm{kg/m^3}$, $\rho_0 = 800\ \mathrm{kg/m^3}$.

A. 0 J
B. 4.9 mJ
C. 9.8 mJ
D. 19.6 mJ

Problem proposed by Alex Jicu

Question 29 – Joule's Experiment



In the shown setup, a mass of m kg falls due to gravity, gravitational constant being g. It falls for h meters, and this causes the water in the beaker on the right to heat up, due to friction caused by the orange box, which is much lighter than m kg. After measurement, we find that the water's temperature increased from $T_i - T_f$. If water's specific heat is c, and the amount of water in the setup is M kg, express the conversion factor between cal and J with the given values. Assume the m kg – mass falls at a constant velocity, and no heat energy is produced, except for in the water.

A. $\frac{1}{1} \frac{\text{cal}}{\text{J}}$

B. $\frac{cM\,(T_f - T_i)}{mgh} \frac{\text{cal}}{\text{J}}$

C. $\frac{c\,(T_f - T_i)}{gh} \frac{\text{cal}}{\text{J}}$

D. $\frac{mgh}{M\,(T_f - T_i)} \frac{\text{cal}}{\text{J}}$

Problem proposed by Doyoon Kim

Question 30 – Smartwatch

Consider two people, A and B, standing in the same point, at the base of an inclined plane of angle $\alpha = 45^{\circ}$. A has a smartwatch on his hand, connected to a phone found in B's pocket.

The connection between the phone and the smartwatch is done via Bluetooth, the communication being done through electromagnetic waves. The smartwatch's detector has a limited sensibility and can only receive electromagnetic waves above a certain intensity, corresponding to a distance of around 20 meters between the two devices.

B starts going up the inclined plane, with a velocity $v_1 = 0.3\ \mathrm{m/s}$, while A moves horizontally, in the same plane as B, in the opposite direction (away from the inclined plane) with $v_2 = 0.7\ \mathrm{m/s}$.

Find the time after which the smartwatch will stop receiving Bluetooth data from the phone, when the two devices will get disconnected.

A. 20.0 seconds
B. 21.4 seconds
C. 28.6 seconds
D. 37.6 seconds

Problem proposed by Alex Jicu