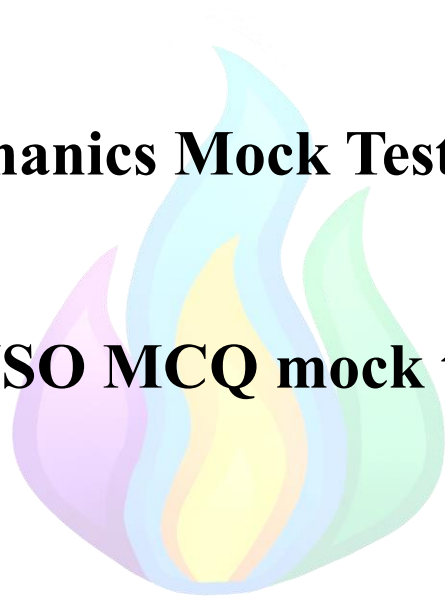


Mechanics Mock Test No. 1

IJSO MCQ mock test



This is an IJSO Mechanics mock test, designed to mimic the style, depth, and difficulty of mechanics 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):

- Alex Jicu (Romania) – Mechanics Mock Test no. 1 Coordinator
- Cabir Abassov (Azerbaijan)
- Doyoon Kim (South Korea)
- Jailson Godeiro (Brazil)
- Niko Habinc (Slovenia)
- Thenura Wickramaratna (Sri Lanka)



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

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

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

Question 1 – A simple trick

A thin rod of length 10 cm is thrown vertically by Timmy with a velocity of 3.00 m/s. At the moment of launch, the rod's leading side is 10 cm above the ground. The rod doesn't rotate in the air. To give the audience a nicer view of the throw, a point light source is hung from the 10.00 m high ceiling on a 9.00 m rope. It is placed at a horizontal distance of 0.8 m from the launch site. When the rod's velocity is equal to 2.25 m/s, how long is its shadow? Ignore air resistance.

- A. 10 cm
- B. 14 cm
- C. 16 cm
- D. The shadow has infinite length.



Question 2 – A ball falling through a slit

A ball with surface area 100 cm^2 is sliding on a frictionless table with velocity v , when it encounters the table's edge. It is now heading towards a wall at a distance of 20 cm from the edge. The wall has a slit of width 9.2 cm. The vertical distance between the slit's upper edge and the table's surface is 16.8 cm. The slit is below the table. What is the approximate range in which v has to be for the ball to fly through the slit? Ignore air resistance.

- A. $0.87 \text{ m/s} < v < 0.93 \text{ m/s}$
- B. $0.87 \text{ m/s} < v < 1.04 \text{ m/s}$
- C. $0.90 \text{ m/s} < v < 0.93 \text{ m/s}$
- D. $0.90 \text{ m/s} < v < 1.00 \text{ m/s}$



Problem proposed by Niko Habinc

Question 3 – An inelastic collision

Two objects are moving along the x-axis. One is moving at + direction with speed of $10.0 \frac{\text{m}}{\text{s}}$ and has a mass of 4.00kg. Another is moving at – direction with speed of $5.00 \frac{\text{m}}{\text{s}}$ and has a mass of 8.00kg. If they collide in a perfectly inelastic collision, how much energy is lost?

- A. 0.00 J
- B. 300 J
- C. 600 J
- D. 900 J



Problem 4 – An adventure on Venus

After the successful colonization of Mars, NASA's next target was Venus. Ifets, the astronaut chosen by NASA to go to Venus, had her body mutated, to be able to withstand the huge atmospheric pressure on Venus ($P_0 = 90\text{atm}$) and to make her lungs able to process venusian air. Lung pressure is measured as a difference between the internal lung pressure and the outside pressure.

Also for Ifets to be able to eat, NASA scientists prepared a special drink SVEPS (Special Venusian Extraterrestrial Protein Shake), which is liquid under the conditions on Venus and has a density of $17 \frac{\text{g}}{\text{cm}^3}$.

Knowing that the acceleration due to gravity on Venus is $8.87 \frac{\text{m}}{\text{s}^2}$, what lung pressure would allow Ifets to drink the SVEPS through a 1 metre long straw?

- A. -1.49atm
- B. $+1.49\text{atm}$
- C. $+88.51\text{atm}$
- D. $+91.49\text{atm}$



Problem 5 – Hanging mass

A 10 kg mass is hung from the ceiling on two ropes. The first rope makes an angle α from the horizontal, while the second one makes an angle β . Knowing that the tangents of the angles obey $\tan(\alpha) + \tan(\beta) = 5.329$ and $F_1 = 21.71$ N, find the force the second rope is pulling on the mass with.

- A. 15.61 N
- B. 88.53 N
- C. 91.42 N
- D. 98.10 N



Problem proposed by Niko Habinc

Problem 6 – Physics in chemistry

A chemist prepares a dilute sulfuric acid solution by mixing 10 volumes of water ($1.00 \frac{\text{g}}{\text{cm}^3}$) with one volume of concentrated sulfuric acid ($1.83 \frac{\text{g}}{\text{cm}^3}$). The density of the obtained dilute sulfuric acid is $1.10 \frac{\text{g}}{\text{cm}^3}$, higher than the one calculated theoretically. That is because the volumes aren't perfectly additive - the final volume of dilute sulfuric acid is lower than the sum of the volumes of water and of concentrated sulfuric acid mixed.

What is the percent volume decrease?

- A. 2.23%
- B. 5.18%
- C. 94.81%
- D. 97.77%



Problem proposed by Alex Jicu

Question 7 – Launching a block

A 10 kg block is fired up an incline of 30° with 10 m/s. The coefficient of friction between this block and the surface of the incline is 0.2. After 4 m, it collides with a block of mass 5 kg. The coefficient of friction between this block and the incline is 0.3. The blocks collide elastically and the lighter block begins moving up the incline. After 2 m, it collides with a spring with stiffness 50 N/m. How much does the spring compress before the block comes to a rest? Assume no air resistance.

- A. 1.70 m
- B. 2.15 m
- C. 2.52 m
- D. 3.19 m



Problem proposed by Niko Habinc

Question 8 – A metal bar

Consider a cylindrical bar AB, with length L . The midpoint of the bar is point M. The half AM of the bar is made of iron (with density $7.80 \frac{\text{g}}{\text{cm}^3}$) and the other half is made of an unknown metal. If C is the center of mass of the bar, it is known that $AC = 0.546L$.

You can use the following density table (all are in $\frac{\text{g}}{\text{cm}^3}$):

Lead	Gold	Silver	Copper
11.35	19.30	10.49	8.90

Find the unknown metal:

- A. Lead
- B. Gold
- C. Silver
- D. Copper



Problem proposed by Alex Jicu

Question 9 – A block on the train

A block is on the front of a train that has a length of 36 m. The train is initially at rest, before accelerating at a constant rate of $7\frac{\text{m}}{\text{s}^2}$, if the block takes 6 seconds to reach the back of the train, what is the coefficient of kinetic friction between the block and the floor of the train? Assume a negligible coefficient of static friction

- A. 0.3
- B. 0.4
- C. 0.5
- D. 0.6

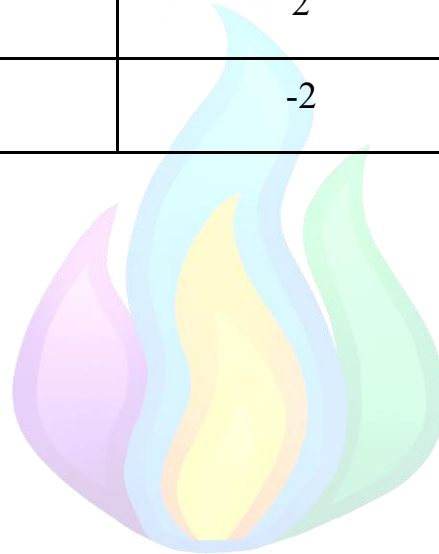


Problem proposed by Jailson Godeiro

Question 10 – Pushing a block

A student exerts a force of 30 N on an initially stationary block of mass 5 kg. The static friction coefficient is 0.8 while the kinetic friction coefficient is 0.4. Find the frictional force and the acceleration of the block

	Frictional Force (N)	Acceleration (ms^{-2})
A	20	2
B	30	0
C	40	2
D	40	-2



Problem proposed by Thenura Wickramaratna

Question 11 – Car racing

A car undergoes a circular trajectory with constant speed (radius of curvature $R = 50\text{m}$), such that it completes two full laps every minute, what should be the total coefficient of static friction between the car's wheels and the ground?

- A. 0.22
- B. 0.36
- C. 0.54
- D. 0.83



Problem proposed by Jailson Godeiro

Question 12 – Efficiency of an engine

A car weighing 800 kg accelerates from 150 km/h to 250 km/h over a distance d . The engine burns $n = 0.8$ g of fuel per second (energy density = 43 MJ/kg). If the time taken is $t = 4$ s, and the actual kinetic energy gain is ΔE , define $F = \Delta E /$ (fuel energy input). What is F ?

- A. 0.18
- B. 0.23
- C. 0.27
- D. 0.33



Problem proposed by Cabir Abassov

Question 13 – Block sliding down a ramp

A block of mass 2.0 kg is placed on a smooth inclined ramp of angle 30° . It is said that the vertical height of the ramp is 5 m. The coefficient of kinetic friction suddenly appears as $\mu_k = 0.2$. The block starts sliding down. How much time does it take for the block to slide down the track?

- A. 1.43 s
- B. 1.84 s
- C. 2.02 s
- D. 2.61 s



Problem proposed by Thenura Wickramaratna

Question 14 – Block going up the ramp

We define the efficiency of an inclined plane as the minimum work required to lift an object at a height h divided by the work done to lift the object from the base of the plane to the same height h (against weight and friction).

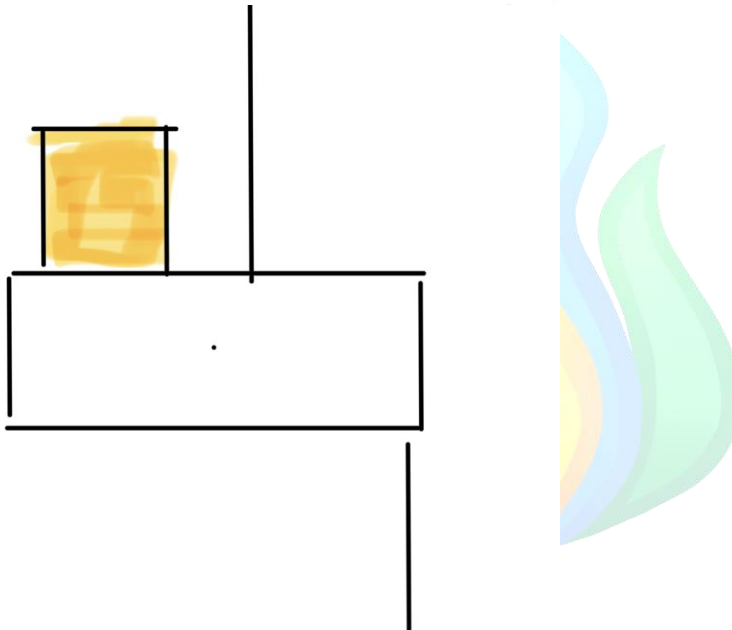
Find the efficiency of the ramp in question 13.

- A. 71.43%
- B. 74.27%
- C. 81.24%
- D. 89.65%



Question 15 – Two blocks being held up

A homogenous white block of mass 3.6 kg is suspended by two strings (see sketch). The upper one is pulling on the block with force F_1 , and the lower one with force F_2 . The horizontal distance between the attachment of the upper string and the centre of the white block is 2 cm, while the distance from the centre of the white block to the lower string is 26 cm. Another block, drawn yellow, with a mass of 2.4 kg, has been placed on the other side of the white block's centre, with its centre of mass at a distance of 10 cm from the white block's centre of mass. Determine the values of F_1 and F_2 .



- A. $F_1 = 60 \text{ N}, F_2 = 0 \text{ N}$
- B. $F_1 = 65 \text{ N}, F_2 = 5 \text{ N}$
- C. $F_1 = 75 \text{ N}, F_2 = 15 \text{ N}$
- D. $F_1 = 82 \text{ N}, F_2 = 22 \text{ N}$

Problem proposed by Niko Habinc

Question 16 – A sinking cube

Scientists are trying to determine the density of a fluid and, in order to do that, they place a cube made of aluminum (mass = 2.7 kg, side length = 10cm) in a container full of this liquid. Assuming that the container lost 300 ml of its liquid after the cube was placed, what is the density of the liquid and the percentage of the cube that floats on the liquid?

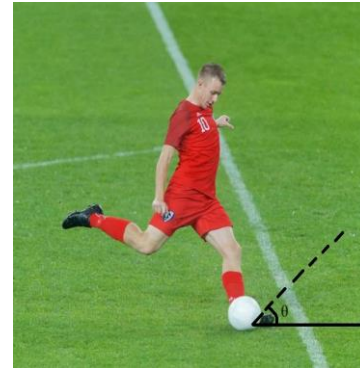
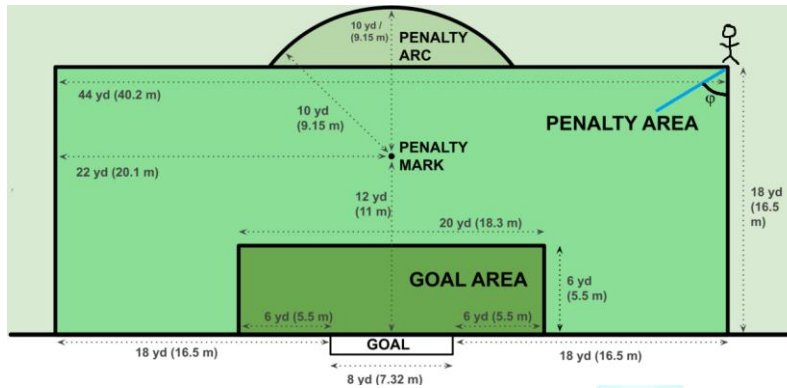
- A. 3 g/cm^3 , 30%
- B. 9 g/cm^3 , 30%
- C. 9 g/cm^3 , 70%
- D. 3 g/cm^3 , 70%



Problem proposed by Jailson Godeiro

Question 17 – Dragus and Tarnovanu

The following pictures show the dimensions of a region of a football pitch, and some markings relevant to the problem:



The stickman is Romanian striker Denis Dragus, found exactly at the corner of the penalty area. He shoots the ball, with an initial velocity $v_0 = 30\text{m/s}$, intending to score. The projection of the ball's trajectory is the blue line. It is known that the angle $\varphi = 50^\circ$ and, in the vertical plane, Dragus shoots the ball with an angle $\theta = 30^\circ$ above the ground. All this happened at the Romanian national team training, with goalkeeper Stefan Tarnovanu in goal. However, he was out of the goal, trying to catch the ball from a corner, so the goal was free! It's up to you to decide what happened to the ball.

Knowing that the height of a football goal is 2.44m and that, during the training, no wind was present and all friction forces are negligible, decide what happened to Dragus's shot:

- A. It went wide (too much to the right/left)
- B. It went above the goal
- C. It went both above and wide
- D. It went in the goal and Dragus scored

Problem proposed by Alex Jicu

Question 18 – A car crash

A car of mass 800 kg collides with a truck of mass 1200 kg. The truck was moving at a velocity of 15 m/s while the car was moving at a velocity of 20 m/s in the opposite direction. After colliding, the truck and the car stick together. Find the final velocity of the system.

- A. 1 m/s
- B. 5 m/s
- C. 18 m/s
- D. 35 m/s



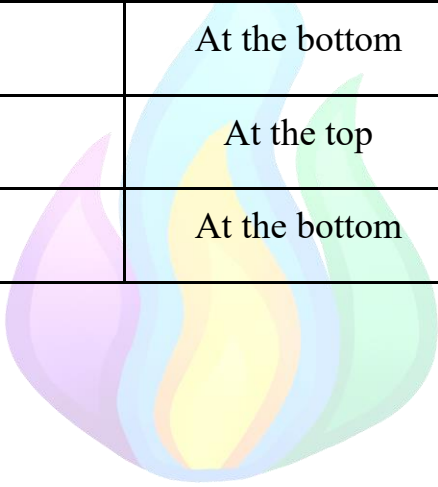
Problem proposed by Thenura Wickramaratna

Question 19 – Swinging a ball

A student ties a 2 kg stone to the end of a rope of length 2 m. The rope has a maximum breaking tension of 300 N. The student begins swinging the stone in a vertical circle, holding the rope from its end.

Determine the speed of the stone at the instant the rope breaks and the position of the stone in the circle (top, bottom, or somewhere in between) at the moment it loses contact.

	Velocity (m/s)	Position
A	16.75	At the top
B	16.75	At the bottom
C	17.88	At the top
D	17.88	At the bottom



Problem proposed by Thenura Wickramaratna

Question 20 – La Vacca Terra Terrisima

La Vacca Terra Terrisima is a cow, shaped like the Earth:



It is known that the average density of a cow (and of La Vacca Terra Terrisima, of course) is $0.89 \frac{\text{g}}{\text{cm}^3}$. Using the universal law of gravitational attraction, what should be the radius of La Vacca Terra Terrisima (assume cows are spheres), such that it has the same surface gravitational acceleration as the Earth?

You might need the following data: the radius of the Earth (6400km), the mass of the Earth (5.97×10^{24} kg) and the acceleration due to gravity on Earth ($9.81 \frac{\text{m}}{\text{s}^2}$)

- A. 6400km
- B. 11700km
- C. 39450km
- D. Not possible, since the acceleration due to gravity is directly linked to density, which is different from that of the Earth

Problem proposed by Alex Jicu

Question 21 – Making an approximation

Let's look at the following setup:

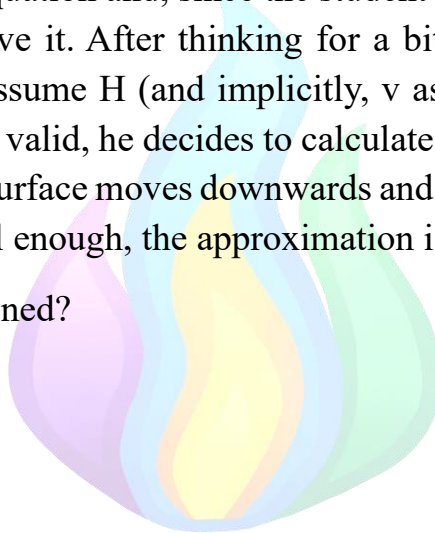
A cylindrical water tank, with cross section area $S = 1\text{m}^2$ is filled with water to a height of $H = 1\text{m}$. The bottom of the tank is perfectly sealed, except for a small circular hole of cross-section area $s = 1\text{cm}^2$. The speed of the water that flows out of the hole is given by Torricelli's law:

$$v = \sqrt{2gH}$$

A student preparing for the IJSO tries to analyze the flow of water from the tank. However, he is met with a problem - the rate at which H decreases is dependent on H - this is a differential equation and, since the student is preparing for the IJSO, he doesn't know how to solve it. After thinking for a bit, he realizes that, for small periods of time, he can assume H (and implicitly, v as well) is constant. To make sure this approximation is valid, he decides to calculate the ratio V/v , where V is the speed at which the water surface moves downwards and v is the speed at which water flows. If this ratio is small enough, the approximation is reasonable to make.

What is the value he obtained?

- A. 10^{-4}
- B. 10^{-5}
- C. 10^{-6}
- D. 10^{-7}



Problem proposed by Alex Jicu

Question 22 – Throwing a ball

A ball is thrown vertically up from the top of a 20 m high cliff with a speed of 10 m/s. Ignore air resistance. How long does it take to reach the ground? Take g to be $10 \text{ m} \cdot \text{s}^{-2}$.

- A. 1 s
- B. 2 s
- C. 3 s
- D. 4 s



Problem proposed by Thenura Wickramaratna

Question 23 – The asteroid belt

In the Solar System, between Mars and Jupiter, a large number of asteroids are found, forming an asteroid belt. They orbit the Sun, similarly to planets, but are much smaller. One recently discovered asteroid is the asteroid 754258 (Anghel, 2016 NW6) with a nearly perfect circular orbit. Its period is $T_1 = 3.68$ years.

At the moment when it was first observed (September 2013), the asteroid was in opposition, meaning it was aligned with the Sun and the Earth in the order Sun – Earth – Asteroid.

Knowing that the Earth and asteroid 754258 orbit in the same direction (clockwise), in what year did the next opposition happen?

- A. 2014
- B. 2015
- C. 2016
- D. 2017



Problem proposed by Alex Jicu

Question 24 – A launcher

A mass of 0.9 kg is attached to a spring with a stiffness of 55 N/m on a surface with a coefficient of both static and kinetic friction of 0.5. The spring is then compressed 30 cm and released. What is the velocity of the attached mass when the spring passes the point of 10 cm compression? Ignore air resistance.

- A. 0.94 m/s
- B. 1.41 m/s
- C. 1.71 m/s
- D. 1.93 m/s



Question 25 – Motion of a boat

A boat of mass m is moving in a steady lake, with a constant velocity v_0 due to its engines. After it stops its engines, at $t = 0$ and $x = 0$ it starts slowing down due to a friction force $F = -kv$, where k is a constant. Using further maths to solve the differential equations of motion, we get:

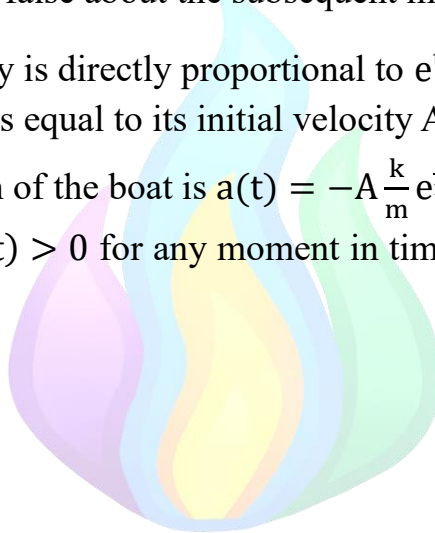
$$x(t) = A \frac{k}{m} (1 - e^{-\frac{k}{m}t})$$

$$v(t) = Ae^{-\frac{k}{m}t}$$

Where A and $e = 2.71$ are constants.

Which of the following is false about the subsequent motion of the boat?

- A. Its kinetic energy is directly proportional to e^{t^2}
- B. The constant A is equal to its initial velocity $A = v_0$
- C. The acceleration of the boat is $a(t) = -A \frac{k}{m} e^{\frac{k}{m}t}$
- D. Even though $v(t) > 0$ for any moment in time, the boat will move only a finite distance



Problem proposed by Alex Jicu

Question 26 – The battle of Borodino

During the battle of Borodino, a soldier in Napoleon Bonaparte's French army wanted to strike a Russian base using a cannon. At first, in order to hit the base located 5 km away, he aimed the cannon at the angle that would give the cannonball its maximum range. However, new intelligence revealed that the front of the Russian army base is actually only 3 km away. The base itself stretches 5 km in width. Determine the range of inclination angles such that the cannonball lands within the base. Assume air resistance and other drag forces to be negligible. Take the cannonball's mass to be 5 kg.

- A. 18.4° to 45.0°
- B. 30.0° to 60.0°
- C. 45.0° to 71.6°
- D. 18.4° to 71.6°



Problem proposed by Thenura Wickramaratna

Question 27 – The battle of Borodino again

The cannonball from the previous problem hit a target that is 4.5 km away. Due to the Russian's luck that day, the cannonball hit the ground. If we assume the ground exerts a constant resistive force of $5 \cdot 10^4$ N. Find the depth of the crater formed due to the cannonball.

You may use any data given in question 27 in order to solve the problem.

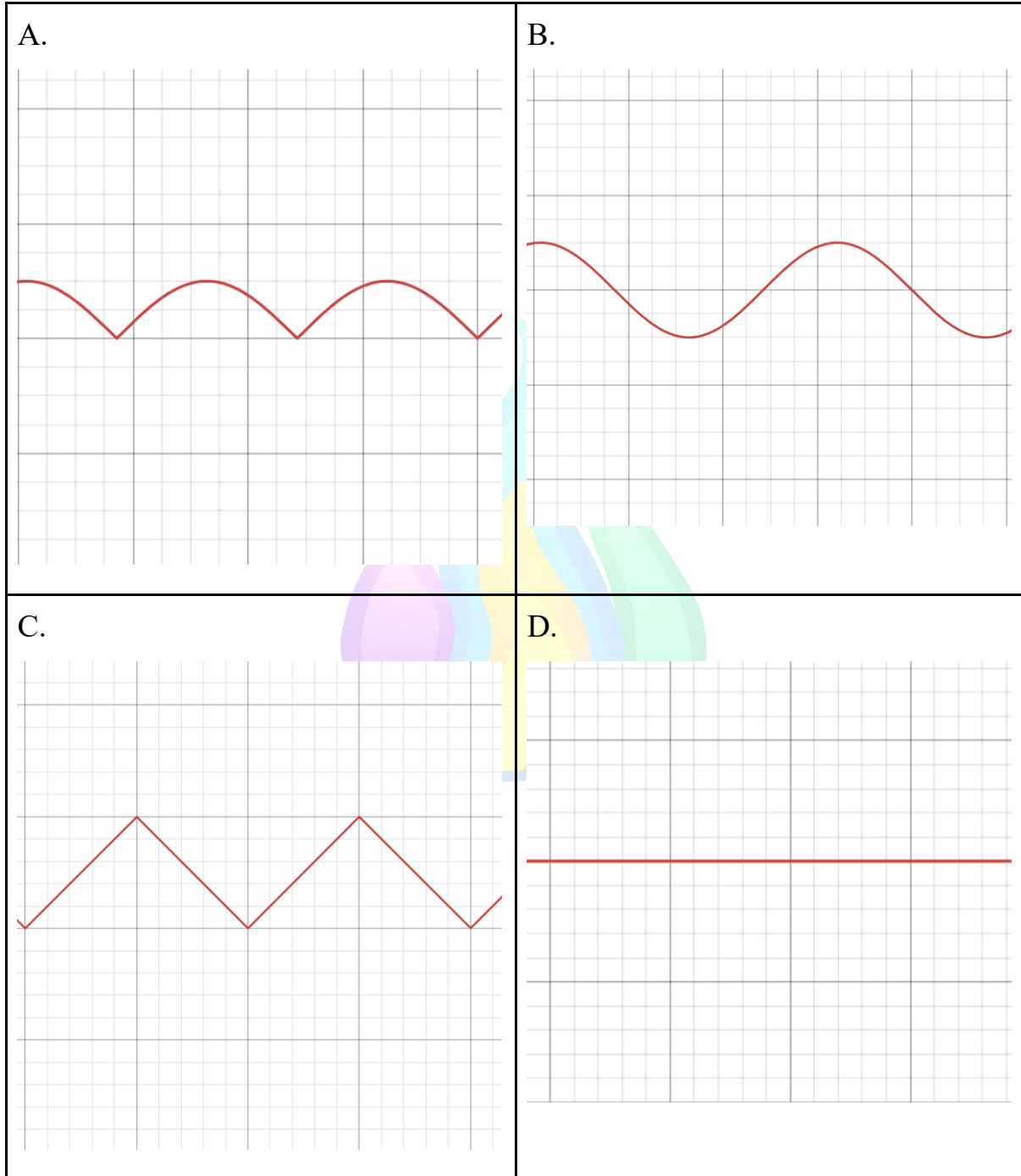
- A. 1.80 m
- B. 2.45 m
- C. 3.61 m
- D. 4.90 m



Problem proposed by Thenura Wickramaratna

Question 28 – A trajectory

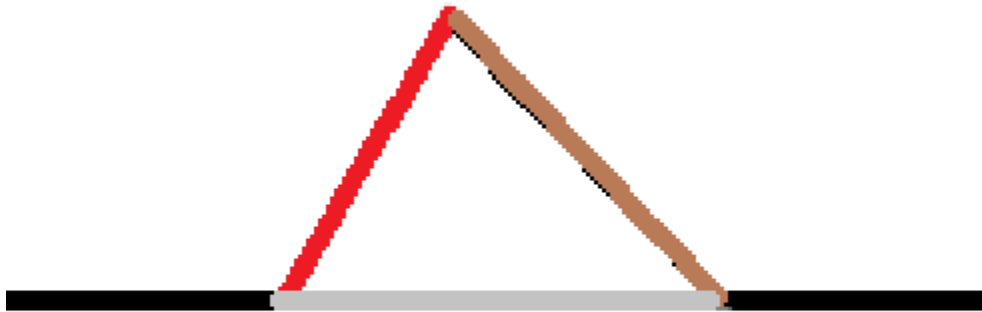
Which of the following graphs most accurately shows the trajectory of the shoe of a runner?



Problem proposed by Alex Jicu

Question 29 – Rotational energy

A door (brown line) opens, moving freely around the place where it's attached to the wall (black lines, the door is attached to the right wall). The free end of the door is attached to the left wall, via an elastic rope with $k = 50 \text{ N/m}$ and negligible relaxed length.



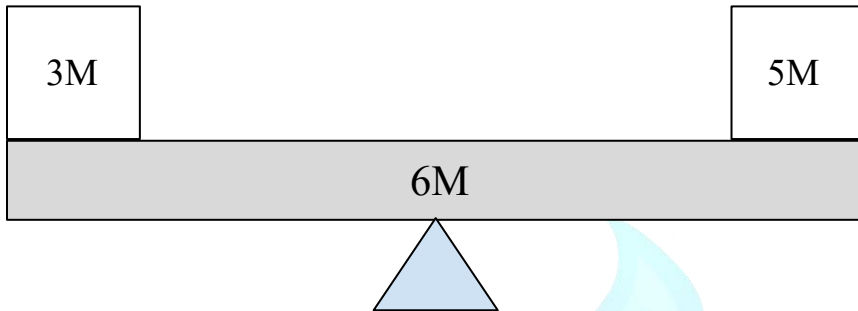
The door is opened such that the opening angle (angle between the door and the gray line) is $\theta = 30^\circ$ and then is left to move freely. If the length of the door is $L = 1 \text{ m}$, find its rotational kinetic energy when it goes through the “closed” position ($\theta = 0$):

- A. 6.70J
- B. 13.4J
- C. 25.9J
- D. 50.0J

Problem proposed by Alex Jicu

Question 30 – A delicate equilibrium

Consider the following setup, where the mass of the rod is not uniformly distributed.



Knowing the length of the rod is 3 m, and that it is pivoted right on its center, where should the center of mass of the rod relative to its center be so that it stays in equilibrium. (Consider the dimensions of the boxes to be negligible)

- A. 0.50 m to the left
- B. 0.50 m to the right
- C. 1.20 m to the right
- D. 1.20m to the left

Problem proposed by Jailson Godeiro