Physics Olympiad Practice Sheet

General problem-solving tips for Physics:

- ✓ A good first step to take when tackling a Physics problem is to organize the information presented to you in the question. Assign suitable labels to all of the identifiable parameters and variables given to you in the problem and take care in properly assigning labels when differentiating between physical quantities (such as initial vs final velocities, positions at differing times, or the directions of vector quantities). Often times a necessary equation or concept will become more apparent after laying out all of the given information.

- ✓ If possible, draw a diagram to help with framing the scenario described in the problem. In many cases, the solution to a Physics problem will open up after constructing a proper diagram.

- ✓ Write comments in good scientific language throughout your problem-solving process. It will make the solution more readable and help in developing your understanding of the concepts involved. It is good practice to avoid presenting solutions that consist of only formulas and numbers.

The following practice problems are given in the style of multiple-choice questions but note that they could also serve as stand alone short answer/calculation style questions requiring written solutions in later rounds of the Olympiad competition.

Practice Problem 1

The neutral point between the Earth and the Moon is the point where the gravitational pull of the Moon is equal to the gravitational pull of the Earth. Ignoring losses, if the energy a $1000\ kg$ spacecraft needs in order to reach the neutral point from the Earth is $6 \times 10^{10}\ J$ and to reach the neutral point from the Moon is $0.25 \times 10^{10}\ J$, then what is the minimum energy needed to send a $1\ kg$ rock from the Moon to the Earth?

A. $0.25 \times 10^7\ J$ ← Correct
B. $5.75 \times 10^7\ J$
C. $6 \times 10^7\ J$
D. $6.25 \times 10^7\ J$

Solution

The rock only needs to be lifted from the Moon up to the neutral point and then it will be able to fall the rest of the way to the Earth under the Earth's gravitational pull. This means that the minimum energy input needed is just the energy to lift the rock from the Moon to the neutral point.

We are told that the energy needed to send a $1000\ kg$ spacecraft from the Moon to the neutral point is $0.25 \times 10^{10}\ J$. Since the rock is 1000 times less massive than the rocket, it will require 1000 times less energy input to achieve the same displacement.

Hence the minimum energy needed to send the rock from the Moon to the Earth will be $0.25 \times 10^7\ J$.

Practice Problem 2

A 750 kg car is moving at a speed of 20 ms^{-1} up a hill. When the car reaches a height of 5 m above the bottom of the hill, it runs out of fuel and the engine stops. The car continues to coast up the slope of the hill until it reaches some maximum height before turning around and rolling back down the side of the hill. What is the maximum gravitational potential energy achieved by the car during this motion? (Ignore frictional forces and air resistance and assume that all movement made along the slope of the hill results in the same change in height above the bottom of the hill.)

A. $0\,J$
B. $37{,}500\,J$
C. $150{,}000\,J$
D. $187{,}500\,J$ ← Correct

Solution

The maximum gravitational potential energy will be achieved when the car reaches its maximum height up the hill, at which point the car briefly stops moving and has zero kinetic energy.

Based on the conservation of mechanical energy, the sum of the kinetic and potential energies at any two points in the car's journey must remain constant.

Taking the initial point to be just as the car runs out of fuel and the final point to be when the car reaches the maximum height, we have

$$KE_i + PE_i = KE_f + PE_f$$

$$\frac{1}{2}(750)(20)^2 + (750)(10)(5) = PE_f$$

$$PE_f = 187{,}500\,J$$

Remarks:

- Often times there exist multiple ways of solving the same problem in Physics. This problem could also have been approached by first calculating the maximum height the car would have reached using Newton's equations of motion and then directly calculating the maximum potential energy. Observe:

  At the maximum height (h_{max}) the car's velocity will be zero. The car starts at a speed of 20 ms^{-1} at a height of 5 m, hence

  $$v^2 = u^2 + 2as$$

  results in

  $$0 = (20)^2 - 2gs$$

  and

  $$s = 20\,m$$

  This means the car continues for another 20 m up the hill in addition to the initial 5 m. Hence $h_{max} = 25\,m$ and finally

  $$PE_{max} = mgh_{max} = (750)(10)(25) = 187{,}500\,J$$

Practice Problem 3

In his commute home from work, Tom drives at a constant speed of 54 km/hr except for a 15 minute stop to buy gas. If his average speed for the entire journey is 45 km/hr, how far did Tom travel?

A. $164.5\ km$
B. $67.5\ km$ ← Correct
C. $45\ km$
D. $100\ km$

Solution

Note that in SI units

$$54\frac{km}{hr} = 54 \times \frac{1000\ m}{3600\ s} = 15\ ms^{-1}$$

similarly

$$45\frac{km}{hr} = 12.5\ ms^{-1}$$

and

$$15\ minutes = 900\ s$$

Average speed $\bar{v}$ is defined as the total distance travelled divided by the total time of travel. We will denote the total distance by D and the total time of travel by T so that

$$\bar{v} = \frac{D}{T}$$

The total time for the journey is the sum of the 15 minute stop time and the time spent travelling at the constant speed of $54\ km/hr$ which we will denote by t_{const}. Hence,

$$T = 900 + t_{const}$$

Since the total distance for the trip D is covered while travelling at the constant speed of $15\ ms^{-1}$, we have that the time spent travelling at the constant speed is

$$t_{const} = \frac{D}{15}$$

By plugging our expression for T and t_{const} into the equation for average speed $\bar{v}$, we can find that

$$12.5 = \frac{D}{900 + \frac{D}{15}}$$

and finally

$$D = 67{,}500\ m$$

Remarks:

- An important first step in this problem is ensuring that all similar quantities are expressed in the same units (for example, in the problem statement, time is expressed in minutes as well as in hours). A good way to ensure homogeneity in your physical quantities is by converting them all to SI units.

- Note that the choice of converting all quantities specifically to SI units (meters and seconds) was not necessary to solving the problem as the question could have been similarly solved by using all distances in km and all times in hours. The important point here is that all values representing measurements of the same physical quantity must be expressed in the same units if they are to be related to one another correctly. The SI unit system just presents the most standard means of making your equations uniform.

Practice Problem 4

A ball inside a of box bounces vertically between the upper and lower surfaces of the box, which are both horizontal and separated by $15\ m$. All collisions are perfectly elastic, and when the ball hits the lower surface, it has a speed of $17.5\ ms^{-1}$. How long does a complete up-down cycle of the ball take?

A. $0.5\ s$
B. $1.5\ s$
C. $2\ s$
D. $3\ s$ ← Correct

Solution

If the ball begins at the lower surface and travels towards the upper surface, we can define its height h above the lower surface at a time t by

$$h = ut - \frac{1}{2}gt^2$$

Since the initial speed of the ball starting at the lower surface is $17.5\ ms^{-1}$, and the final height of the ball will be $15\ m$ upon reaching the upper surface, we can arrive at the following equation:

$$15 = 17.5t - \frac{1}{2}gt^2$$

By substituting $g = 10\ ms^{-2}$ we have a quadratic equation for t which we can solve to find that the time to travel from lower to upper surfaces is:

$$t_{up} = 1.5\ s$$

By symmetry, the time for the ball to go from the upper surface to the lower surface is the same as the time to travel from lower to upper surface. This means that the final time for the complete up down cycle is

$$t_{up-down} = 2 \times 1.5\ s = 3\ s$$

Remarks:

- Note that we had two roots to the quadratic equation for t, and we selected the root $t = 1.5\ s$ and not the other root $t = 2\ s$ for our solution. This is because in our scenario the ball is restricted to a box and hence it cannot rise any higher than the $15\ m$ ceiling of the box.

- If instead the ball was not contained, then it would have been possible for the ball to continue rising to a maximum height of $15.3125\ m$ against the force of gravity before turning around and returning to our specified height of $h = 15\ m$ on its way back down to the ground. In this altered scenario the ball would achieve the height of $15\ m$ twice: once (at $t = 1.5\ s$) during its travel upwards, and then a second time (at $t = 2\ s$) on its way back downwards. For the given problem the $t = 2\ s$ scenario has no relevance.