Solution to IPhyC 2025 Qualification Round Problems

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Solution to Problem 1

The turtle moves at a constant speed of 0.2 km/h.

The human is 100 times faster than the turtle. So, the human's speed is

$$100 \times 0.2 = 20 \text{ km/h}$$

The total length of the race is 1 km.

Since the turtle is given a head start of 980 m, it does not need to cover the whole distance. It only has to travel

$$1000 - 980 = 20 \text{ m} = 0.02 \text{ km}$$

At a speed of 0.2 km/h, the time taken by the turtle to reach the finish line is

$$t_{\text{turtle}} = \frac{0.02}{0.2} = 0.1 \text{ h}$$

The human starts from the very beginning and runs the full 1 km. At a speed of 20 km/h, the time taken by the human is

$$t_{\text{human}} = \frac{1}{20} = 0.05 \text{ h}$$

Now comparing the two times, we see that

$$t_{\text{human}} < t_{\text{turtle}}$$

This means the human reaches the finish line first. So, even with a very large head start, the turtle cannot win against the human's much higher speed.

Solution to Problem 2

The mass $m = 2$ kg is hanging at rest, so nothing in the system is moving. This tells us that the system is in equilibrium, meaning the total force at the junction of the strings must be zero.

Let the tension in each of the two upper strings be T. Since the pulleys are ideal, the string connected to mass M also has the same tension T.

First, look at the vertical string holding the 2 kg mass. Because the mass is not moving, the tension in this string must balance its weight:

$$T_v = mg \tag{1}$$

Now focus on the junction where the three strings meet. The two upper strings are placed symmetrically, and each one makes an angle $\alpha = 80°$ with the vertical.

Because of this symmetry, the horizontal components of the two tensions cancel each other out. So we only need to think about the vertical components.

The vertical component of the tension from one upper string is

$$T \cos\alpha$$

Since there are two such strings, the total upward force is

$$2T \cos\alpha$$

For the junction to stay in equilibrium, this upward force must balance the downward force mg:

$$2T \cos\alpha = mg \tag{2}$$

Solving this equation for T, we get

$$T = \frac{mg}{2\cos\alpha} \tag{3}$$

Now consider the mass M. It is also at rest, so the tension in its string must be equal to its weight:

$$T = Mg \tag{4}$$

Substituting the expression for T from earlier,

$$Mg = \frac{mg}{2\cos\alpha} \tag{5}$$

The factor g cancels out from both sides, leaving

$$M = \frac{m}{2\cos\alpha} \tag{6}$$

M = m$\frac{}{2\cos\alpha}$

Putting in the given values $m = 2$ kg and $\alpha = 80°$,

$$M = \frac{2}{2\cos 80°} = \frac{1}{\cos 80°}$$

Using $\cos 80° \approx 0.174$,

$$M \approx 5.7 \text{ kg}$$

So, the required mass is

$$\boxed{M \approx 5.7 \text{ kg}}$$

Solution to Problem 3 Question (a): Number of air molecules in the bottle

The bottle is cylindrical, so its volume is

$$V = \pi r^2 h \tag{7}$$

Given $r = 3$ cm $= 0.03$ m and $h = 20$ cm $= 0.20$ m,

$$V = \pi(0.03)^2(0.20) \approx 5.65 \times 10^{-4}\ \mathrm{m}^3$$

At ground level, the pressure is $P = 100$ kPa $= 1.0 \times 10^5$ Pa and the temperature is $T = 20°\mathrm{C} = 293$ K.

Using the ideal gas law $PV = NkT$, where $k = 1.38 \times 10^{-23}$ J/K,

$$N = \frac{PV}{kT} \tag{8}$$

Substituting the values,

$$N = \frac{(1.0 \times 10^5)(5.65 \times 10^{-4})}{(1.38 \times 10^{-23})(293)} \approx 1.4 \times 10^{22}$$

So, the bottle contains approximately

$$\boxed{N \approx 1.4 \times 10^{22}\ \text{air molecules}}$$

Solution to Problem 3 Question (b): Pressure at the top of the mountain

The bottle is closed and rigid, so the number of molecules and the volume remain constant. This means that

$$\frac{P}{T} = \text{constant} \tag{9}$$

The temperature at the top of the mountain is

$$T_2 = 16°\mathrm{C} = 289\ \mathrm{K}$$

Using

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \tag{10}$$

we solve for P_2:

$$P_2 = P_1 \frac{T_2}{T_1} \tag{11}$$

Substituting the values,

$$P_2 = (100\ \mathrm{kPa})\frac{289}{293} \approx 98.6\ \mathrm{kPa}$$

Therefore, the pressure inside the bottle at the top of the mountain is

$$\boxed{P_2 \approx 99\ \mathrm{kPa}}$$

The pressure drops slightly because the air cools as we go higher.

Solution to Problem 4

The ball is released from rest and slides without friction, so only gravity accelerates it. Since the angles are measured with respect to the vertical, the component of gravity along a slope inclined at an angle θ is $g\cos\theta$.

Motion on the first slope:

On the first slope, the acceleration is

$$a_1 = g\cos\theta_1 \tag{12}$$

The ball starts from rest and travels a distance x_1.

Using the kinematic relation $x = \frac{1}{2}at^2$,

$$x_1 = \frac{1}{2}g\cos\theta_1\, t_1^2 \tag{13}$$

Solving for t_1,

$$t_1 = \sqrt{\frac{2x_1}{g\cos\theta_1}} \tag{14}$$

The speed of the ball at the bottom of the first slope is

$$v_1^2 = 2a_1x_1 = 2gx_1\cos\theta_1 \tag{15}$$

$$v_1 = \sqrt{2gx_1\cos\theta_1} \tag{16}$$

Motion on the second slope:

On the second slope, the acceleration is

$$a_2 = g\cos\theta_2 \tag{17}$$

The ball enters this slope with initial speed v_1 and travels a distance x_2. Using $x = ut + \frac{1}{2}at^2$,

$$x_2 = v_1 t_2 + \frac{1}{2}g\cos\theta_2\, t_2^2 \tag{18}$$

Substituting v_1,

$$x_2 = \sqrt{2gx_1\cos\theta_1}\, t_2 + \frac{1}{2}g\cos\theta_2\, t_2^2 \tag{19}$$

Solving this quadratic equation for t_2 gives

$$t_2 = \frac{\sqrt{2gx_1\cos\theta_1}}{g\cos\theta_2}\left(\sqrt{1 + \frac{x_2\cos\theta_2}{x_1\cos\theta_1}} - 1\right) \tag{20}$$

Total time:

The total time is $T = t_1 + t_2$. Factoring out $\sqrt{\frac{2x_1}{g\cos\theta_1}}$,

$$T = \sqrt{\frac{2x_1}{g\cos\theta_1}}\left[1 + \frac{\cos\theta_1}{\cos\theta_2}\left(\sqrt{1 + \frac{x_2\cos\theta_2}{x_1\cos\theta_1}} - 1\right)\right] \tag{21}$$

This is the required expression for the time needed to reach the end of the second slope.

Solution to Problem 5

Sunlight looks white because it contains all the colors of visible light mixed together. When this light enters the Earth's atmosphere, it starts to interact with tiny air molecules, mainly nitrogen and oxygen.

These air molecules are much smaller than the wavelength of visible light. Because of this, a process called ***Rayleigh scattering*** takes place. In this process, shorter wavelengths are scattered much more than longer ones.

The strength of this scattering depends strongly on wavelength and can be written as

$$I \propto \frac{1}{\lambda^4} \tag{22}$$

This means that light with a smaller wavelength is scattered much more strongly. As a result, blue and violet light are scattered far more than red light.

Even though violet light is scattered more than blue, the sky does not look violet. This is because our eyes are not very sensitive to violet light, and some of it is also absorbed high up in the atmosphere.

Because of this, most of the scattered light that reaches our eyes from all directions is blue. That is why the sky looks blue during the day.

At sunrise and sunset, sunlight has to travel a much longer distance through the atmosphere. During this long journey, most of the blue light is scattered away from the direct path. The light that finally reaches us is therefore richer in red and orange colors.

So, the sky appears blue during the day due to stronger scattering of shorter wavelengths, while at sunrise and sunset it often looks red or orange because the blue light has already been scattered out.

Important Notice

Figure 1: The Moon surrounded by numerous stars, captured by the author

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