1. Since the block is released from an unstressed spring, we can find the amplitude of the oscillation from the equilibrium:

\[ F_g = F_s \implies mg = kA \implies A = mg/k = 10m. \]

Since the period runs 40 m, we see that 100 m travel is in fact 2.5 perfect oscillations, we can find the time by multiplying 2.5 with the time it takes for each oscillation, i.e. its period. The period of the oscillation is given by

\[ T = 2\pi \sqrt{\frac{m}{k}} = 2\pi \sqrt{\frac{20}{20}} = 2\pi \]

\[ 2.5T = 50\pi \approx 15.7 \text{ s} \]

2. Recall that the escape velocity is given by aligning kinetic energy with gravitational energy

\[ \frac{1}{2}mv^2 = \frac{GM_pm}{r_p} \]

\[ \frac{1}{2}v^2 = g_p r_p = g_p r_e \]

\[ v = \sqrt{2g_p r_e} = \sqrt{2(5.5)(6378)} = 264.8 \text{ m/s} \]

3. The linear mass density \( \mu \) of the string can be computed as

\[ \mu = \frac{m}{L} = \frac{0.0015}{0.65} \approx 0.0023 \text{ kg/m} \]

The relation between velocity of the wave and tension is

\[ v = \sqrt{\frac{T}{\mu}} \]

With wavelength of a fundamental frequency given by \( \lambda = 2L \), we can set up the equation

\[ f = \frac{v}{\lambda} = \frac{1}{2L} \sqrt{\frac{T}{\mu}} \]

\[ 330 = \frac{1}{2(0.65)} \sqrt{\frac{T}{0.0023}} \]

\[ T = 424.71 \text{ N} \]

4. The 5 kg mass, \( m_A \), will fall and 2 kg mass, \( m_B \), will be lifted with the same magnitude in acceleration. We can model the net forces of the two blocks using tension of the string \( T \):

\[ F_{\text{net},A} = m_A a = m_A g - T \]

\[ F_{\text{net},B} = m_B a = T - m_B g \]
Equating the tension, we have

\[ m_A g - m_A a = m_B g + m_B a \]
\[ a(m_A + m_B) = (m_A - m_B)g \]
\[ a = \frac{m_A - m_B}{m_A + m_B} g = \frac{3}{7}(9.8) = 4.2 \text{ m/s}^2 \]

5. Using conservation of angular momentum and an initial angular momentum of 0, we have

\[ 0 = I_{you}\omega_{you} + I_{disk}\omega_{disk} \]

We can compute the momentum of inertia of the disk using parallel axis theorem,

\[ I_{you}\omega_{you} = -(m_{disk}r^2 + \frac{1}{2}m_{disk}R^2)\omega_{disk} \]
\[ \omega_{you} = \frac{m_{disk}\omega_{disk}}{I_{you}} \left( r^2 + \frac{1}{2}R^2 \right) = \frac{0.5(200)}{8} \left( 1 + \frac{0.3^2}{2} \right) = 13.1 \text{ rad/s} \]

6. Using the motion equations in its angular form

\[ 0 = \omega_0 - \alpha t = \omega_0 - \frac{\tau}{I} t \]
\[ t = \frac{I\omega_0}{\tau} = \frac{2}{5}mR^2 \left( \frac{\omega_0}{\tau} \right) = \frac{40(0.04)}{5} \left( \frac{20}{1} \right) = 6.4 \text{ s} \]

7. By conservation of energy, we have

\[ mv_{i,1}^2 + mv_{i,2}^2 = mv_{f,1}^2 + mv_{f,2}^2 \]
\[ (140^2 + 20^2) = v_{f,1}^2 + v_{f,2}^2 \]

By conservation of momentum, we have

\[ mv_{i,1} + mv_{i,2} = mv_{f,1} + mv_{f,2} \]
\[ 140 + 20 = v_{f,1} + v_{f,2} \]

Note that we don’t have to convert unit since mass doesn’t play a role anymore. Solving the the equation by and notice that the speed in fact merely swapped:

\[ v_{f,1} = v_{i,2} \text{ and } v_{f,2} = v_{i,1} \]

Therefore, their difference is 120 km/h.

8. Recall conservation of angular momentum:

\[ 0 + \Delta L = L_f \]
\[ m_{boy}v_{boy}R\sin(\theta) = (I_{disk} + I_{boy})\omega \]
\[ (43)(2.2)(1.6)\sin(90) = \left( \frac{1}{2}(200)(1.6)^2 + (43)(1.6)^2 \right) \omega \]
\[ \omega = \frac{43(2.2)}{1.6(100 + 43)} = 0.413 \text{ rad/s} \]
9. Breaking $v_0$ into $x,y$ components:

\[
\begin{align*}
  v_{0,x} &= \cos(\theta)v_0 = 5.161 \\
  v_{0,y} &= \sin(\theta)v_0 = 3.613
\end{align*}
\]

While $v_x$ is not affected over time, $v_y$ decreases velocity by gravity

$$v_{f,y} = v_{0,y} + at = 3.613 - 9.8(0.12) = 2.437$$

Finally the speed is calculated by Pythagoras norm

$$|v| = \sqrt{5.161^2 + 2.437^2} = 5.707 \text{ m/s}$$

10. Since the ball is only subjected to uniform acceleration motion during vertical free fall, we can use the the 1D motion formula as follows

$$y = y_0 + v_0t + \frac{1}{2}at^2$$

$$y - y_0 = v_0t - \frac{1}{2}gt^2$$

$$0 = v_0t - \frac{1}{2}gt^2 = v_0 - \frac{1}{2}gt$$

$$v_0 = \frac{1}{2}gt = \frac{1}{2} \cdot 9.8 \cdot 10 = 49 \text{ m/s}$$

11. The center of mass is is $6 - 3.2 = 2.8 \text{ m}$ left of S2. The weight of plank needs to black the block on the right by

$$r_{center}F_{g,plank} = rF_{g,block}$$

$$22(2.8)g = r(53)g$$

$$r = \frac{22(2.8)}{53} = 1.16 \text{ m, from right of S2}$$

12. The situation described is essentially $1/4$ of a period of a pendulum system. For an angle as small as $10^\circ$, $t$ is simply

$$t = \frac{1}{4}T = \frac{\pi}{2} \sqrt{\frac{l}{g}} = \frac{\pi}{2} \sqrt{\frac{2}{9.8}} = 0.709 \text{ s}$$
13. \[
\vec{L} = \vec{r} \times \vec{p} = \vec{r} \times m\vec{v} \\
= (2\hat{i} + 3\hat{j} + 5\hat{k}) \times (7\hat{i} + 11\hat{j} + 13\hat{k}) \\
= 14(\hat{i} \times \hat{i}) + 21(\hat{j} \times \hat{i}) + 35(\hat{k} \times \hat{i}) \\
+ 22(\hat{i} \times \hat{j}) + 33(\hat{j} \times \hat{j}) + 55(\hat{k} \times \hat{j}) \\
+ 26(\hat{i} \times \hat{k}) + 39(\hat{j} \times \hat{k}) + 65(\hat{k} \times \hat{k}) \\
= -21(\hat{i} \times \hat{j}) + 35(\hat{k} \times \hat{i}) + 22(\hat{i} \times \hat{j}) \\
- 33(\hat{j} \times \hat{k}) - 26(\hat{k} \times \hat{i}) + 39(\hat{j} \times \hat{k}) \\
= (22 - 21)(\hat{i} \times \hat{j}) + (35 - 26)(\hat{k} \times \hat{i}) + (39 - 33)(\hat{j} \times \hat{k}) \\
= 6\hat{i} + 9\hat{j} + \hat{k}
\]

14. The frequency that the prey will hear is
\[
f_1 = f_0 \left(\frac{v_{snd}}{v_{snd} \pm v_{src}}\right) = 100 \left(\frac{343}{333}\right) = 103\text{kHz}
\]

And the wave bounced back to the bat is given by
\[
f_2 = f_1 \left(\frac{v_{snd} \pm v_{obs}}{v_{snd}}\right) = 103 \left(\frac{353}{343}\right) = 106\text{kHz}
\]

15. Pick either of them to be a pivot. By equating the centripetal acceleration with gravity, we can compute the angular velocity of the orbit.
\[
ma_c = m\omega^2 r = \frac{Gm^2}{r^2}
\]
\[
\omega^2 = \frac{Gm}{r^3}
\]
\[
|\omega| = \sqrt{\frac{Gm}{r^3}} = \sqrt{\frac{(6.674 \cdot 10^{11})(1 \cdot 10^3)}{(120 \cdot 10^3)^3}} = 0.621 \text{ rad/s}
\]

To compute period from angular velocity, we use
\[
T = \frac{2\pi}{0.621} = 10.11 \text{ s}
\]