1) You are working on a top secret DARPA (Defense Advanced Research Projects Agency) program known as the distributed robotics program. You are given the task of designing a robot that can jump 0.7 meters high and can make 14 jumps using its onboard power supply, which is a hydrogen fuel cell.

The accompanying graph depicts the Force as a function of time. The robot begins its jump at 0.1 s and leaves the surface at 0.3 s.

a) What must be the robot’s speed as it leaves the ground in order to attain the 0.7 meter height?

b) What is the maximum possible mass of the robot?

c) How much energy must be stored in the fuel cell in order for the robot to complete 14 jumps?

d) How many “g-forces” does the robot experience during the time from 0.1 second to 0.3 seconds? In other words, what is the acceleration?

e) What is the speed of the robot when it lands after a jump?
2) A 3 g (0.003 kg) bullet traveling at 300 m/s is fired into a 50 g (0.050 kg) block of wood where it embeds itself. The wood is attached to a spring as shown in the figure. The spring constant of the spring is 5.3 N/m. Assume that the wood is initially at rest at x = 0 and the spring is in the unstretched equilibrium position. Also, assume that the wood is sliding on a frictionless plane.

a) What is the speed of the wood with the bullet in it immediately after the bullet embeds itself into the wood?

b) What is the maximum compression of the spring some time after impact?

c) What was the kinetic energy of the bullet before impact?

d) What was the kinetic energy of the wood with the bullet in it immediately after the bullet embedded itself into the wood?

e) Was the total mechanical energy conserved? If not, explain?
3) It is another great day at the races. In lane 1, we have Harry the hoop. In lane 2, we have Cilia the cylinder. In lane 3, we have Bella the ball. And in lane 4, we have Bob the block.

Here are their statistics.
Harry the hoop: $I = m r^2$, mass = 3 kg, radius = 0.15 m.
Cilia the cylinder: $I = \frac{1}{2} m r^2$, mass = 3 kg, radius = 0.15 m.
Bella the ball: $I = \frac{2}{5} m r^2$, mass = 7 kg, radius = 0.15 m.
Bob the block: mass = 3 kg, Cube, 0.15 m on each edge.

They are released at the same time to move down an inclined plane. All of the lanes are the same, except Bob’s lane is frictionless, so it slides without friction down the incline. The other lanes have friction, so they all roll without slipping. The top of the inclined plane is 0.3 meters above the bottom of the inclined plane. Take the gravitational potential energy to be zero at the bottom of the inclined plane.

\( \textbf{a}) \) Who reaches the bottom first?
Who reaches the bottom second?
Who reaches the bottom third?
Who reaches the bottom fourth?
Are there any ties?

It is not necessary to provide extensive calculations if you give convincing arguments for your answers.

\( \textbf{b}) \) What is the speed of Bob the block at the bottom?

\( \textbf{c}) \) What is the \textbf{rotational (angular)} speed of the Harry the hoop at the bottom?

\( \textbf{d}) \) What is the total mechanical energy (all kinetic and potential energies) of Bob the block at the bottom?

\( \textbf{e}) \) What is the total mechanical energy (all kinetic and potential energies) of Harry the hoop at the bottom?
A two dimensional elastic collision occurs between identical subatomic particles. Particle A has an initial velocity of $3 \times 10^6$ m/s in the x-direction. Particle B is initially at rest. After the collision, particle A moves off at an angle $\alpha$ above the x-axis. Particle B also moves off with an angle $\alpha$ (the same angle), but below the x-axis. Both particles have the same speed (magnitude of velocity) after the collision. The mass of each particle is 1 atomic mass unit ($1.66 \times 10^{-27}$ kilograms.)

a) What is the speed of each particles (remember they have the same speed) after the collision?

b) What is the angle $\alpha$?

c) What is the total combined momentum of both particles after the collision?

d) What is the total combined kinetic energy of both particles after the collision?

e) If the two particles stuck together, after the collision, turning the collision into a one-dimensional inelastic collision, what would be the total combined momentum of the particles, now stuck together, after the collision.