

NYU General Physics 1—Problem set 7

Problem 1: Gasoline and olive oil are both substances with great chemical energy content per unit mass.

(a) In the case of gasoline, the chemical energy is mainly in carbon bonds. If you assume that gasoline is *entirely* carbon atoms, and each one releases 4 eV of energy when it is combusted, how much energy per unit mass is there in gasoline? Get an answer in MJ per kg and compare to what you find on *Wikipedia*. How far off are our assumptions?

(b) Now convert your answer to kcal per g and compare it to what is written on the “Nutrition Facts” label on an olive oil bottle. How close are you? It should be close, I think, because biofuel is made from things like olive oil!

(c) Now assume that a car moving at speed $v = 75 \text{ mi h}^{-1}$ encounters an air resistance force of $\rho A v^2$, where ρ is the density of air and A is the cross-sectional area of the car, about 2 m^2 . How much work does it take to move the car 30 mi at this speed?

(d) If a car with these properties was *perfectly efficient*, how many miles per gallon would it get? What does this make you think about the future of energy-efficient cars?

Problem 2: A (magical) perfect ball of mass $m = 0.7 \text{ kg}$ is dropped from a height $h = 0.9 \text{ m}$ onto a hard surface, off of which it bounces perfectly. It then continues to bounce forever. Make a plot, labeling carefully the time and energy axes, of the kinetic energy of the ball as a function of time, and of the gravitational potential energy of the ball as a function of time. Assume that the bounces (the times in contact with the floor) are extremely short (negligible). Now also plot the sum of the kinetic energy and the potential energy (the total energy) as a function of time. For all three plots, label relevant times and energies. You have to make a choice about the “zero” of potential energy, right?

For extra fun: Make the bounces last a short time Δt and plot also the “elastic” potential energy in the ball!

Sanity check: This problem is impossible because in real life, each bounce will be shorter than the previous bounce. Why? Where does that energy go?

Problem 3: A New York City Bus moving down Broadway at 15 m s^{-1} hits a small elastic rubber ball, which happens to be very close to at rest

just before the collision. The bus has a mass of 2×10^4 kg and the ball has a mass of 0.02 kg.

(a) Draw a diagram showing the bus and the ball and their velocities, immediately *prior* to the collision. Compute the kinetic energies and the momenta of the bus and the ball. For the momenta, you will have to choose a direction for your coordinate system.

(b) Draw the same diagram, but now from the point of view of the driver of the truck next to the bus, who is driving at the exact same speed. That is, draw the diagram in the “reference frame” in which the bus is at rest before the collision. In this frame, the bus is stationary and the ball is moving. Again, compute the kinetic energies and momenta. Why are they different from what you got in part (a)? Aren’t energy and momentum conserved?

(c) Staying in this new reference frame, imagine now how the ball bounces off the bus. The collision will be elastic, but you don’t really have to calculate anything: What happens when a tiny ball bounces elastically off a huge bus? Draw a diagram showing the bus and the ball and their velocities, in the frame of the bus, immediately *after* the collision. Compute the kinetic energies and momenta.

(d) If you made a certain very useful approximation, then you probably didn’t conserve momentum in part (c). Why not? In detail, the velocity of the bus is affected by the collision. By how much does the velocity of the bus change, approximately, in the collision? If you *did* conserve momentum in part (c), then just report here the change in velocity of the bus.

(e) Now take what you had in part (c) and re-draw it back in the original reference frame, which is that of the stores on Broadway. Compute the kinetic energies and momenta. How fast is the rubber ball moving after the collision? Don’t try the experiment.

(f) After the collision, the ball is moving fast, but its mass is much smaller than that of the bus. At the end of the problem, what fraction of the total system momentum and kinetic energy are in the ball?