NYU Physics I—Problem Set 5

Due Thursday 2016 October 13 at the beginning of lecture.

Problem 1: NYC had a hot summer in 2016, with most buildings running air conditioning on a thermostat continuously. To save energy, NYU asked their employees to conserve energy in various ways, some of which we might take issue with. Here's an uncontroversial one: You should take the stairs, not the elevator.

But is that uncontroversial? In the parts that follow, make sure you are explicit about your assumptions, and that your assumptions are reasonable. If you are concerned with reasonableness, do some experiments and make some observations.

(a) How much potential energy does a typical NYU employee generate if he or she climbs 10 stories of stairs?

(b) How fast does a healthy, young (say 30s), typically abled NYU employee climb this many stairs?

(c) Compare the kinetic energy of the employee while climbing to the potential energy gain. Which dominates our considerations?

(d) What is the average horsepower mechanical output of this NYU employee steadily climbing stairs? Why do you not need to consider the kinetic energy *at all* in this part, and that ignoring it isn't even an approximation?

(e) For every kcal (look up the calorie and the kcal; what are called "calories" in nutrition are actually kcal) of mechanical energy generated, a healthy, fit human also generates about 7 times more in metabolic load; that is, you burn some 8 times your mechanically computed power in food calories. How many kcal did the employee burn going up the 10 stories?

(f) Now imagine (correctly) that all that metabolic energy gets dumped into the building atmosphere and needs to get corrected by the building air conditioning. Air-conditioning units are very inefficient; they produce multiple BTU (or kcal or J or kWh) of heat for every BTU (or kcal or J or kWh) of cooling they do. Look up efficiencies for typical AC systems and figure out what load an employee puts on the AC by climbing this far.

(g) [Not for credit!] For *extremely deep reasons*, an elevator can't be perfectly efficient either. Can you think of some of these reasons? Prof Hogg knows at least three unbeatable physical constraints. The relevant question for us is: Does an elevator burn more than eight times the mechanical work it is doing, and does it drop that load inside the building AC system? If you want, do some research to understand this. The "nicest" assumption you can make about the elevators is that they are always crowded, so you are only looking at the *marginal* cost of bringing up one more person.

Problem 2: A student of mass $m_{\mathrm{student}} = 80\,\mathrm{kg}$ stands at rest next to a block of ice of mass $m_{\mathrm{ice}} = 320\,\mathrm{kg}$, also at rest, on a frictionless frozen lake. The student pushes on the block until the block is moving away from the student at $1.5\,\mathrm{m\,s^{-1}}$ (that is, until $|\vec{v}_{\mathrm{ice}} - \vec{v}_{\mathrm{student}}| = 1.5\,\mathrm{m\,s^{-1}}$). How much work did the student do? Give your answer in J. Don't forget to conserve linear momentum! *Hint:* All that work went into kinetic energy. *Another hint:* One of the hard things about this problem is that I am giving you the *relative* velocity and not the absolute velocity. How are you going to deal with that? Spend some time visualizing the problem before writing equations.

Problem 3: A machine at a packaging facility places stationary packages of mass m onto a horizontal conveyor belt that is moving packages steadily and horizontally at speed v. Once placed on the belt, the packages start moving at speed v; that is, they are rapidly accelerated.

(a) What is the momentum change for each package as it gets placed on to the belt, and what is the kinetic energy change?

(b) Imagine that the machine places packages steadily onto the belt, with time intervals T between packages. Compute the average mechanical power required by the belt by dividing the kinetic energy per package by the time interval between packages.

(c) Now compute the average force the belt is applying to the packages by dividing the momentum per package by the time interval between packages. This is possible, because momentum is force per unit time (if that is a surprise, do some library or web research).

(d) Power is force times velocity (dot product, really); so the force answer can be turned into a power answer and compared to the power you computed above.

(e) Do you have a discrepancy? If so, why? Which answer is more correct?