Homework 2

Converting energy from one form to another

Due Friday Jan 19 at 5pm

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1. Wind resistance

You may have previously encountered this formula for wind resistance:

$$F_D = \frac{1}{2}\rho v^2 C_D A \qquad (1)$$

where ρ is the density of air, v is the velocity of the object relative to the air, C_D is the drag coefficient and A is the cross-sectional area of the object. Show that the work done by this drag force on a moving object is equivalent to the simple model we derived in class for a car driving at constant velocity.

Note: When we analyze this aerodynamics question using forces, we say "wind resistance" or "drag force". When we analyze this question in the language of energy transfer, we say "energy is transferred to the surrounding air". I like the energy transfer approach because it demystifies wind resistance and allows you to derive Eqn. 1 from first principles.

2. Hydrocarbon fuels

Hydrocarbon fuels have an energy density of about 10 kWh/kg. This means that burning 1 kg of hydrocarbon fuel releases 10 kWh of thermal energy. There are many forms of hydrocarbon fuel: gasoline for cars, wood for campfires, and butter/chocolate/croissants etc. for people.

a) Using the simple model for driving at constant velocity, estimate how much gasoline a typical car uses to drive 70 miles at 70 mph. Express your answer in both kg and gallons.

b) Using the same model for constant-velocity transportation, change the inputs to be appropriate for a bicycle. The efficiency of humans turning fuel into mechanical work is about 30%. How many kilograms of chocolate (or similar fuel) would a bicycle rider need to consume to travel 70 miles at 15 mph?

3. Could the Sun be a ball of gasoline?

Imagine the Sun is powered by burning gasoline. We know from radiometric dating of rocks on Earth (and the Moon and Mars), the solar system is more than 4 billion years old. What mass of gasoline would be needed to power the Sun at a rate of 4×10^{26} J/s for 4 billion years?

Sense-making: Make a comparison Compare to the actual mass of the Sun.

4. Comet hits a planet

Adapted from Six Ideas that Shaped Physics Unit C (C6R.2)

In 1994, fragments of comet Shoemaker-Levy struck the planet Jupiter, each traveling at a speed of about 60 km/s immediately before impact. These impacts were closely studied by scientists on earth. However, the fragment sizes were too small to measure directly via telescope imaging. An estimate of the total energy released by the impact of fragment G was 4×10^{22} J (equivalent to 100 million typical atomic bombs). Use this information to estimate fragment G's size (diameter). Assume that fragment G was made of rock. Don't be too precise.

Sense-making: Make a comparison – Identify one or two common objects with a similar size to your estimate of fragment G. Does your estimate seem reasonable?

5. Rocket launch

Adapted from Six Ideas that Shaped Physics Unit C (C7S.4)

A rocket is fired vertically from the surface of the earth. Its engines fire only briefly, and then the rocket continues to coast upward. The rocket is going fast enough (has enough kinetic energy) to escape the gravity of earth.

The instant the rocket engines switch off, the rocket has kinetic energy, $\frac{1}{2} m_{rocket} v_i^2$, and gravitational potential energy $-GM_{earth}m_{rocket}/r_{earth}$. As the rocket coasts into outer space, the sum of kinetic energy and gravitational potential energy stays constant.

a) Calculate the smallest v_i such that the rocket escapes the gravity of earth. Check that your answer is reported in an appropriate unit.

b) Sense-making: Tell a conceptual story - Write a narrative description of the energy transformation (from one form to another) as the rocket coasts away from earth. Depict gravitational potential energy and kinetic energy at different times using bar graphs. Discuss how the velocity of the rocket is changing as the distance from earth increases.

6. Thermal energy in the earth's climate

Thermal energy is stored in all materials on earth, including air, water and rocks. For diatomic gases at room temperature (for example, nitrogen gas) the internal energy is

$$U = (5/2)Nk_B T,$$

where N is the number of gas molecules, k_B is Boltzmann's constant and T is temperature.

a) Use the mass of an N_2 molecule to construct an expression for the internal energy of nitrogen gas in terms of temperature and the total mass of gas.

b) Estimate the total mass of the Earth's atmosphere by considering the air pressure at sea level (about 100 kPa) and the radius of the earth (about 6000 km). Note that the air pressure at sea level is caused by the downward force of gravity ($F_g = mg$) acting on the air above.

c) For liquid water at room temperature

$$U = (18/2)Nk_B T$$

where N is the number of water molecules. Use the mass of a water molecule to write an expression for the internal energy of liquid water in terms of temperature and the total mass of water.

d) Apply parts a, b, and c and to assess the validity of this statement:

> "Between 1955-2010, the temperature of the top 2000 meters of the ocean rose by about 0.05 C. If the same amount of heat that has gone into the top 2000 meters of the ocean between 1955-2010 had gone into the lower 10km of the atmosphere, then the Earth would have seen a warming of about 20°C."

Is this statement reasonable, or ridiculous?