Problem Set 1 (PHY231H) - Due: Oct 25th, 2010

1. **Human genome:**

(i) What is the estimate for the number of protein coding genes in the human genome?

(ii) Only about 1% of the human genetic material codes for proteins, the rest are 'junk DNA' which do not code for any proteins. Assume each protein is about 30 amino acids strung together, and each amino acid is coded for using 3 base pairs (A-T or G-C) on the DNA. Based on this information, estimate the total length of the human genome in terms of number of base pairs.

(iii) Each base pair molecule along the DNA double helix takes up about $3.3\mathring{A}$. Based on this, what is the length of the human genome? ($1\mathring{A} = 10^{-10}m$).

(iv) Find out the radius of a typical human cell. What is the typical radius of the nucleus of the cell which stores the genome (all the genetic material)?

(v) Can you think of an interesting (physics) problem to study based on these calculations?

2. **Staying warm:**

(i) Roughly, how much energy does an adult human consume each day (24 hour day, and measure energy in kilocalories)? (Note: Dietary recommendation for "Calorie consumption" is actually in kilocalories!). How much is one calorie in Joules (SI units)?

(ii) Based on the daily consumption, what is the 'power consumption', i.e., energy consumed per second (Joules per second = Watts)?

(iii) Specific heat C of a material is the amount of energy needed to raise the temperature of 1gm of the substance by 1K. What is the specific heat of the human body given that the human body is mostly constituted of water? If all the consumed energy leads to heating the human body, how much would you raise the temperature of a typical adult (say with a mass of about 70 kg) during the 24 hour day?

(iv) While overheating may seem to be a big problem [based on the solution to part (iii)], we must keep in mind that the body needs to stay warm given that the surroundings are typically cooler than the body. A rough estimate of the heat loss rate (P = energy lost per unit time in Watts) of a body is given by the Stefan Boltzmann law of "Blackbody Radiation":

$$P = A\sigma(T^4 - T_s^4). \tag{1}$$

Here T is the body temperature, and T_s is the temperature of the surroundings (both measured in Kelvin), A is the body surface area, and $\sigma = 5.6 \times 10^{-8} W m^{-2} K^{-4}$. Since T and T_s are close to each other when measured in Kelvin, we can simplify this further, and write it as

$$P \approx 4A\sigma T_s^3 (T - T_s). \tag{2}$$

Derive this simpler formula from the Stefan Boltzmann law.

(v) The area of the human skin may be crudely estimated as $2m^2$. Assume $T \approx 37$ Celsius, and $T_s \approx 20$ Celsius, convert these to Kelvin, and find P. Compare this answer with the solution to part (ii). Comment on what you learn from this exercise.

(vi) If we set $P = C\frac{dT}{dt}$, we obtain a rate at which the temperature of a body with specific heat C drops with time. This means

$$\frac{dT}{dt} = \gamma (T - T_s) \tag{3}$$

where $\gamma = 4A\sigma T_s^3 / C$. In terms of γ, T_s, find the general solution to this differential equation in terms of the initial body temperature $T(t = 0) = T_0$.