PHYC10007 Physics for Biomedicine

Tutorial Sheet 6 — *Heat and Conduction*

Discussion/Conceptual questions

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1. If you heat a substance, is it possible for the temperature of the substance to remain unchanged?
2. On a cold day, when you touch a metal door knob, it feels very cold, but if you touch the wood of the door it does not feel so cold. Explain.
3. If you pinch out a candle flame with your fingers, is it better to wet them first? Explain.
4. Which will cause more severe burns to your skin: 100 °C water or 100 °C steam?
5. You put 1 kg of ice at 0°C together with 1 kg of water at 50°C. What is the final temperature?

   Data: $L_f = 3.33 \times 10^5$ J/kg; c(water) = 4190 J/kg °C

   a) 0°C
   b) between 0°C and 50°C
   c) 50°C
   d) greater than 50°C

Problem-solving questions

6. The Earth receives about 430 W/m^2 from the Sun, averaged over the whole surface, and radiates an equal intensity back out into space (that is, the Earth is in equilibrium). Assuming the Earth is a perfect emitter ($\varepsilon = 1$), estimate its average surface temperature.

7. Protein denatures at about 45°C, not much above the temperature of a high fever.
   a) Calculate the energy required to denature the protein in an adult male of 64kg, if his initial temperature is 37°C and all his temperature regulating processes fail.
   b) Now assume his temperature regulating processes are again working, in particular he is perspiring at 30g of water per minute, which leads to 1200W of heat dissipation. What external temperature is required to overcome that 1200W, by radiative heating alone, if his temperature remains at 37°C? Assume he is unclothed and has an effective area of 1.8m^2.
8. Ice packs are used in physiotherapy for injuries, to reduce inflammation and bruising. An ice pack typically starts at T_1 = 0 °C with all the water frozen, and is no longer useful once it warms to T_2=5 °C. The average rate at which an ice pack warms up is R = 80 W. How long is it useful, if the heat pack is 0.5kg?

9. "Heat packs" are used in physiotherapy for muscle injuries, to provide thermal energy to keep a muscle warm. A heat pack typically starts at T_1 = 70 °C, and is no longer useful once it cools to T_2=40 °C. The average rate at which a heat pack loses thermal energy is R = 40 W. How long is it useful, if the heat pack is
   a) 1kg of water
   b) 1kg of steel.
   c) Which would you use?

10. How do capillaries cool the body? Capillaries are 0.75 mm below the skin. Assuming a temperature difference of 0.5 °C from the capillaries to the surface, what is the body's total heat loss by conduction? Compare to resting metabolism. Assume total surface area is 1.8m^2 and k = 0.2 W/m

11. Eskimos are renowned for living in igloos. Indeed, ice is a reasonable thermal insulator, and inside an igloo the temperature is readily maintained at 0 °C even though the external temperature might be –70 °C.

    a) A healthy Eskimo maintains a body temperature of 37 °C. If the ambient temperature inside the igloo is 0 °C, what is the ***net*** energy loss rate from one (undressed) Eskimo, assuming radiative energy loss only? Take the total surface area of the Eskimo to be that of a cylinder of 1.6m height and 15cm radius, and skin emissivity of 0.97.

b) Write an expression for the mass of ice that would be melted for some heat transfer Q and hence estimate the mass of ice melted due to the heat radiated by one (undressed) Eskimo per hour, ignoring conductive loss to the air and through the igloo walls.