Physics 103c

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Order of Magnitude Physics

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Problem Set 7

Due at *beginning* of class *Wednesday, 24 May 1995*

Homework Problems:

1. Heat Loss By Swimmers

   Do world class distance swimmers overheat? Note that the Prandtl number of water, $Pr \equiv \nu/\kappa \approx 6$.

2. Boundary Layer Drag

   Consider the drag on a sphere moving through a homogenous fluid. What fraction of the total drag is contributed by friction associated with the boundary layer? Assume that the Reynolds number is in the regime, $1 \ll Re \leq 10^5$, such that the boundary layer is laminar but the wake is turbulent.

3. A freight train moving at 45mph sees a car on the tracks ahead, and locks its brakes.
   a) Estimate the stopping distance (the coefficient of friction for steel sliding on steel is 0.4).
   b) Estimate the contact area between each wheel and the rails.
   c) Estimate the depth to which heat diffuses during the time the contact area of each wheel takes to slide its own length.
   d) Thus derive an approximate equation for the peak surface temperature of the rails, and estimate its value. Is melting (lubrication!) a problem?
   e) For how long after the train stops will the rails remain warm* to the touch?

4. Skating: the coefficient of steel sliding on ice at temperatures between -11C and -5C is about 0.005.
   a) Estimate the ratio of power a speed skater uses to overcome sliding friction compared to the power to overcome wind resistance (the world records in 5km and 10km speed skating are held by Koss, respectively $6^{\mathrm{m}}35^{\mathrm{s}}$ and $13^{\mathrm{m}}30^{\mathrm{s}}$).
   b) Estimate the forward force that must be applied by the skating strokes to maintain speed against the total drag. You should find that this is large compared to the sliding friction, but small compared to the body weight. How is speed skating possible if the forward force must be large compared to the sliding friction (banana peel effect)? Are wind resistance and sliding friction the only relevant dissipation?

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* We will *not* post bail for students attempting to determine the answer to parts (a) and (e) by parking their cars on a railway level crossing and waiting upstream!

5. More skating: the origin of the low coefficient of skating friction on ice is poorly understood. Decide whether you think two explanations commonly given are likely or not:

   a) *Pressure melting.* Since ice is less dense than water, pressure reduces the melting temperature. Estimate the change in melting temperature under the pressure of a skate supporting a human. Do you think ice at -11C will liquefy?

   b) *Frictional heat melting.* Use your results of problem 3 to estimate the change in surface temperature of the ice during skating. Could that melt ice at -11C?

6. Invent a problem of your own.