
Problem Set 3Due **in class** Monday 20 April 2009**Homework Problems:**

1. **Natural Frequency of Millikan.** Estimate the natural frequencies of oscillation of Millikan library in the N-S and E-W directions.
2. **Cooking Vessels.** Cooking dishes are composed of special glasses that have low coefficients of thermal expansion. For example, the linear coefficient of thermal expansion α , in units of inverse centigrade degree, is 1×10^{-5} for commercial (“window”) glass, 3×10^{-6} for pyrex, and 8×10^{-7} for vycor. Why is ordinary glass inappropriate for cooking vessels? Be quantitative.
3. **Geothermal sources.** The temperature in the Earth’s crust increases at a rate of 20 K per kilometer of depth.
 - a) If the sun turned off, how cold would the Earth’s surface be after it reached its new steady state?
 - b) Could geothermal sources provide a solution to the world’s energy problem?
4. **Climbing?** You are going mountain climbing, and can carry 10kg of climbing equipment, in the form of either a ladder or a rope. Estimate the maximum length of
 - a) ladder (anchored at the bottom)
 - b) rope/wire (anchored at the top)that can support your weight. Assume both are made of steel. For simplicity, think of the ladder as a pole or tube of any cross-sectional size and shape which you think will optimise your results, with small protrusions on which to place your feet.
5. **Choo, choo, clackety clack** You may have wondered why the rails on which old trains run have gaps between sections, which make the familiar clackety clack as the train wheels run over the gaps. The steel rails weigh 64kg per meter of length. Although actually they have an I-shaped cross-section, for simplicity in this problem assume they have a square cross-section of side a and length L between sections. You may also neglect the fact that railroad track consists of two parallel rails, and just consider a monorail.
 - a) Find a in cm.
 - b) Assume the rails were firmly clamped to bedrock at both ends. On a hot summer day the temperature rises 20 C above the temperature on which the rails were clamped. Compute the compressive force F_c on the clamped rails both as a general formula, and also estimate F_c as a weight in tons.
 - c) In fact most rails are not clamped to bedrock, but just attached to wooden ties 18cm deep and 2.5m long embedded in a bed of gravel. How long (in m) would a section of such unclamped rail have to be to actually develop the full compressive force F_c you estimated in part (b)?

- d) How long (in m) could a section of unclamped rail be before it would buckle (in railroad lingo, “sun kink”) on the hot summer day, if the impeding force due to gravel on the sides of the ties is neglected?
- e) Explain why railroad regulations require that rail be anchored at temperatures close to the maximum expected summer temperatures. If this is done, how large are the gaps between 20m rail segments on cold winter days? If, to avoid clickety clack gaps, the rail segments are continuously welded together on hot days, will they be in danger of breaking on cold winter days?
- f) When the railroad regulations about rail anchoring temperature are neglected, spectacular derailments due to track buckling can occur -e.g. <http://www.nts.gov/publicctn/2003/RAR0302.pdf>. In the NTSB report on this derailment of an Amtrak train (leading to 4 fatalities and 36 serious injuries), the NTSB listed the following factors: (1) the derailment occurred when the rail temperature was $> 100\text{F}$, while the track had been anchored when the temperature was $\sim 60\text{F}$ (in violation of regulations requiring anchoring at $> 100\text{F}$), (2) there was only half as much gravel on the sides of the ties as regulations required, (3) the track was on a curve, and (4) a heavy coal train had passed over the track a few minutes before the passenger train which derailed. Explain qualitatively how each of these contributed to the buckling of the rails that caused the disaster.