February 1992

Ph.D. Qualifying Examination
Fusion Engineering

1. (20 min.) Compute the minimum value of $n\tau_E$ ($n \equiv$ total ion density; $\tau_E \equiv$ energy confinement time) if a plasma consisting of a 50-50 mixture of D and T is to reach breakeven ($Q = E_f/E_I = 3$) at a temperature of 15 Kev. All of the $_2He^4$ particle energy can be assumed to contribute to heating of the plasma. State your assumptions.

$$<\sigma v>_{15\ KeV} = 2.5 \times 10^{14} \frac{cm^3}{s}$$

$$D + T = {}_2He^4 + n$$
$$(3.5\ MeV) \quad (14.1\ MeV)$$

$$P_{rad}\left(watts/cm^3\right) = 5.35 \times 10^{-31}\ n_e^2\ (KT)_e^{1/2}$$

$$\text{where } n_e [=] \left(\frac{electron}{cm^3}\right)$$

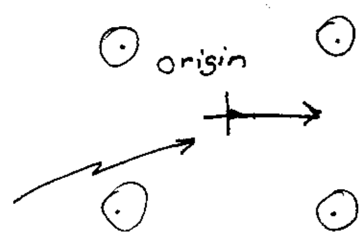
$$KT [=] (KeV)$$

$$1\ MeV = 1.6 \times 10^{-13}\ Joule$$

2. (20 min.) a.) Find the gyroradius, gyrofrequency, and direction of rotation for a proton in the uniform magnetic field shown below:

mass of a proton = 1.672×10^{-27} kg
charge of a proton = 1.6×10^{-19} Coulomb

$\vec{B} = 10T\ \hat{z}$



initial proton position and velocity

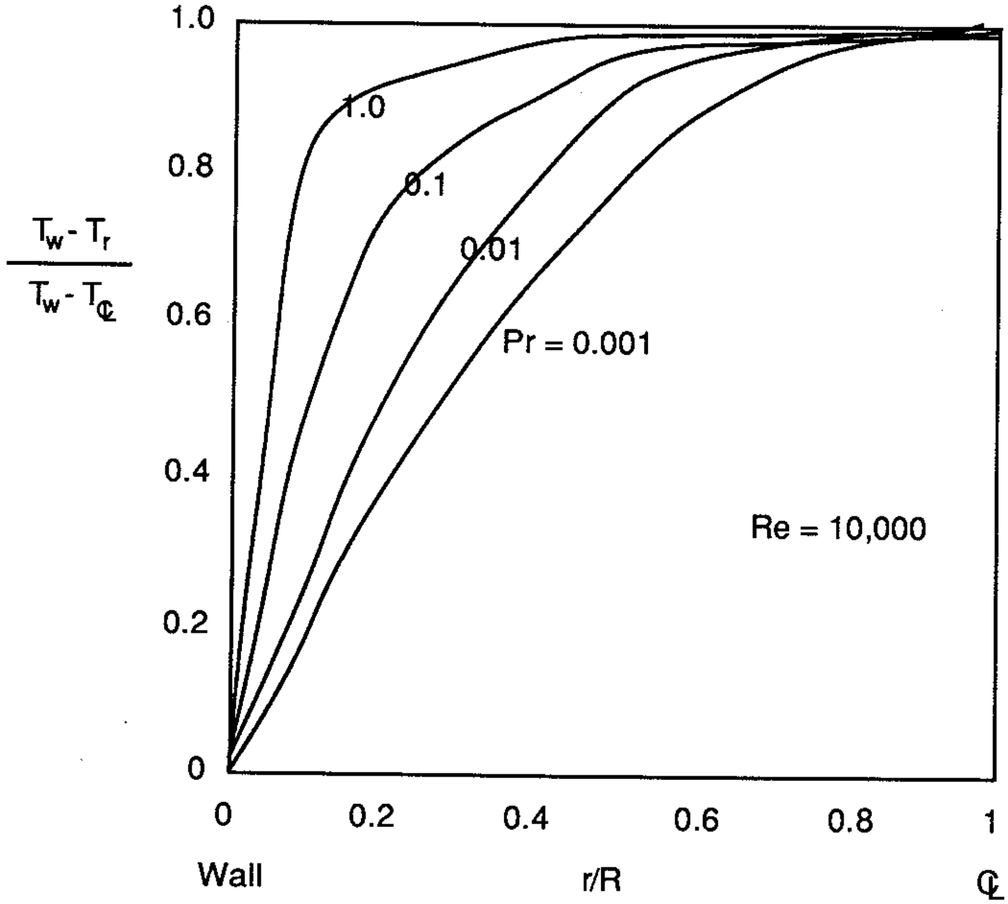
@ $t = 0$
$x = 0$ $\quad v_x = 2 \times 10^5$ m/sec
$y = 0$ $\quad v_y = 0$
$t = 0$ $\quad v_z = 0$

b.) Find the magnitude and direction of the proton's drift velocity due to gravity $\left(\vec{g} = -9.8 \frac{m}{s^2} \hat{y}\right)$

c.) Describe how a proton would drift if it is assumed to be confined in a simple mirror device.

3. (20 min.) A cyclic heat engine operates with Carnot efficiency between heat reservoirs with temperatures T_1 and T_2 ($T_2 > T_1$). T_2 is fixed, but T_1 may vary. If Q_2 (heat input) is unlimited, but Q_1 (heat rejection) is equal to kT_1^4 where k is a constant, what temperature ratio, T_2/T_1, will yield the maximum work output?

4. (20 min.)



Normalized Temperature versus Position

r - radial position in tube | R - tube radius

T_w - tube wall temperature | T_r - fluid temperature at position r

$T_{℄}$ - coolant temperature at channel centerline

Re - $\rho vD/\mu$ | $Pr = \mu c_p/k$

Various fluids have been proposed for fusion reactor blanket cooling including gases, water, and liquid metals. The accompanying figure is a plot of normalized fluid temperature versus position for flow in a tube with a Reynolds number of 10,000 and different Prandtl numbers. At operating conditions in a blanket cooling system the Pr number for lithium is 0.004 and for water 0.8.

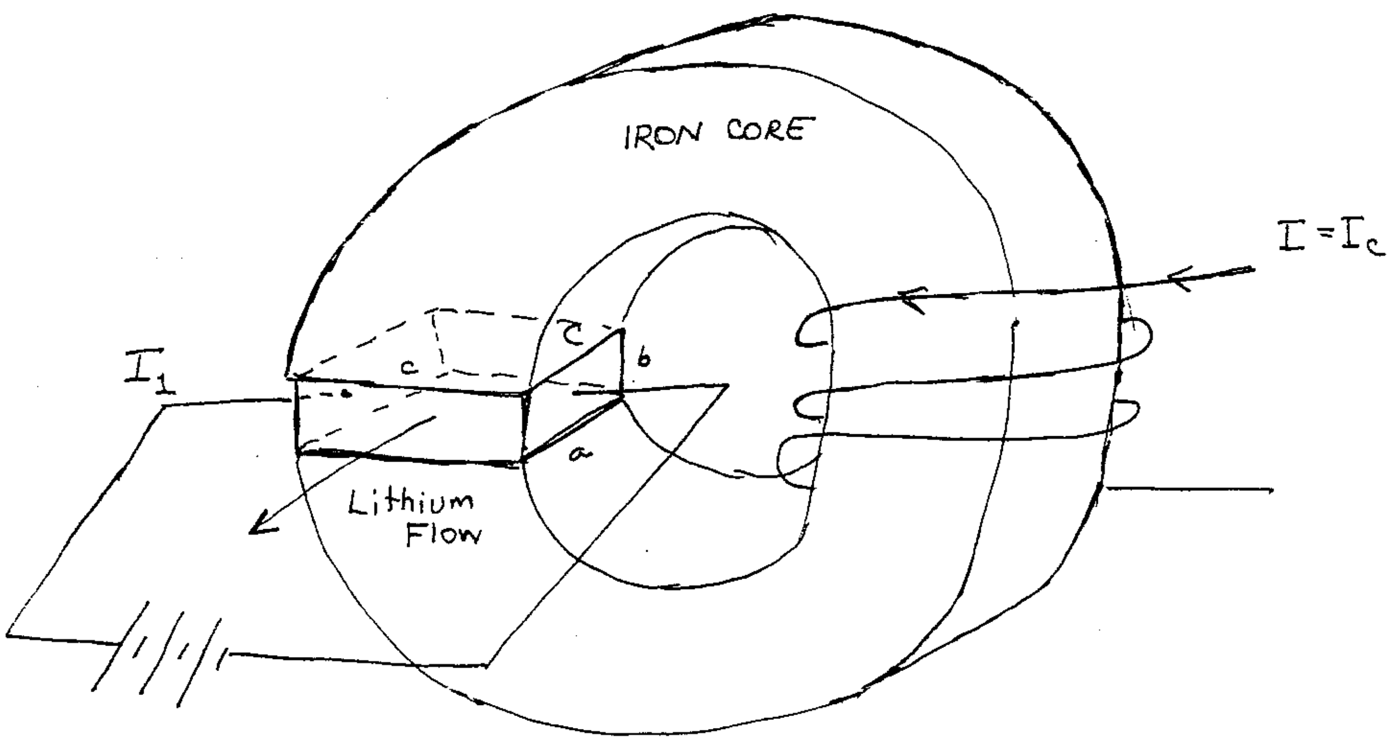
The temperature profiles for water and lithium differ. Explain why this is the case based on the properties of the fluids and the hydrodynamics of the flow.

5. (20 min.) a.) Consider a 20 keV beam having a density of n_1 deuterons/m^3 that is incident on a thin stationary target having a density of n_2 tritons/m^3. The microscopic cross section for D-T fusion is 6×10^{-2} barns. Find the reaction rate density for D-T fusion.

b.) Consider a 20 keV D-T plasma having the same particle densities as in part a. The reaction rate parameter is 4×10^{-22} m^3/sec. Find the reaction rate density for D-T fusion.

c.) Compare the results of parts a and b and explain, using physically based arguments, why they are different.

6. (20 min.) It has been suggested that D-T fusion reactors could be cooled with molten metallic lithium. The lithium would be circulated using the head provided by an electromagnetic pump. A schematic of such a pump is shown below:



a.) Explain how a force is created to cause the lithium to flow.

b.) Given that the magnitude of the magnetic flux density through the pump cross section is B Tesla, and that the electric current flow through the lithium containing section of pump is uniform and equal to I_1 (as for the pump shown in the above figure), what is the pressure that acts on the lithium?

c.) Describe the advantages and disadvantages of electromagnetic pumps as compared to centrifugal pumps.