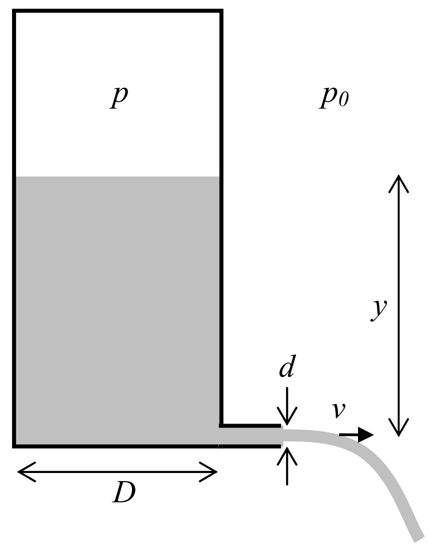
Thermal Physics, Physics 224 **Midterm exam 1** **January 31, 2003**
Winter 2003
Instructor: David Cobden **4 pages (printed on both sides)**

You have 50 minutes. Begin and end on the buzzer. Be sure to write your name on every page. Answer all questions. Write all your working on these question sheets. Watch the blackboard for corrections during the exam. This is a closed book exam. You are allowed one sheet (two sides) of notes. You are allowed a simple calculator. Throughout this exam, you will get credit for giving algebraic answers wherever possible as well as numerical answers.

Question I. Fluids [50 points total]

Part A.
The vessel sketched on the right is a vertical cylinder with diameter D containing water (grey, density ρ) to a depth y. A high pressure p is maintained in the air above the water, which is allowed to squirt out at into the open air (pressure p_0) through a short, open-ended pipe of diameter d at the bottom.



1. [4] Sketch streamlines of the water flow.

2. [8] Use Bernoulli's principle to *estimate* the squirting speed v.

3. [4] What approximations or assumptions did you make in applying this principle?

4. [6] At what rate does the depth of the water y decrease?

5. [6] What is the criterion that determines whether the flow in the pipe is turbulent?

Part B.

6. [6] State Archimede's principle for finding the buoyant force on an object. What is the center of buoyancy, and how do you find it?

7. [10] A cube of ice (density $\rho_i = 900\ \text{kg/m}^3$), of side L, is floating in the sea (density $\rho_w = 925\ \text{kg/m}^3$) with one face upwards. A polar bear of mass $M = 200$ kg stands on top of it. What is the minimum size L for his feet to be just above the water, assuming the ice cube does not tip over?

8. [6] Why is it virtually impossible for the bear to maintain his position on this mini-iceberg without it rolling over and dumping him in the water?

Question 2. Temperature and kinetic theory [50 points total]

Part C.

9. [8] Sketch and annotate the interaction potential *U(r)* between two adjacent atoms spaced by distance *r* in a solid. Explain why most solids expand as the temperature is increased.

10. [8] A concrete highway is built of slabs which are 12 m long at 20° C. The coefficient of linear expansion is $\alpha = 12\times10^{-6}$ (°C)$^{-1}$. How wide should the expansion cracks between the slabs be at 20° C to prevent buckling if the range of temperatures throughout the year is -30° C to +50° C?

11. [8] The modulus of concrete under compression is $E = 2.0\times10^{10}$ N/m^2. If the slabs are mistakenly laid end-to-end with no expansion cracks at 20° C, what pressure will develop between them (equal to the stress within them) at 30° C?

Part D.

The electrons moving in some solid behave as a low-density gas of free particles in thermal equilibrium at room temperature $T = 20°$ C. Their number density is $n = 10^{27}$ m^{-3}, and each has a mass $m = 10^{-4}$ a.u. (1 a.u. = mass of one hydrogen atom; $k_B = 1.38\times10^{-23}$ J/K; $N_A = 6.02\times10^{23}$).

12. [8] Estimate the pressure exerted by the electron gas on a surface of the solid.

13. [8] Calculate the rms velocity, v_{rms}, of one of these electrons.

14. [8] Is the pressure exerted by a real gas greater than, equal to, or less than that which would be exerted by a gas with the same short range interactions but no long range interactions? Why, in words? Show how this is accounted for in the van der Waals equation.