CHAPTER 3

Figures

These figures are from

Understanding the properties of matter

by Michael de Podesta.

For more details see **www.physicsofmatter.com**

Figure 3.1 An integrating analogue to digital converter.

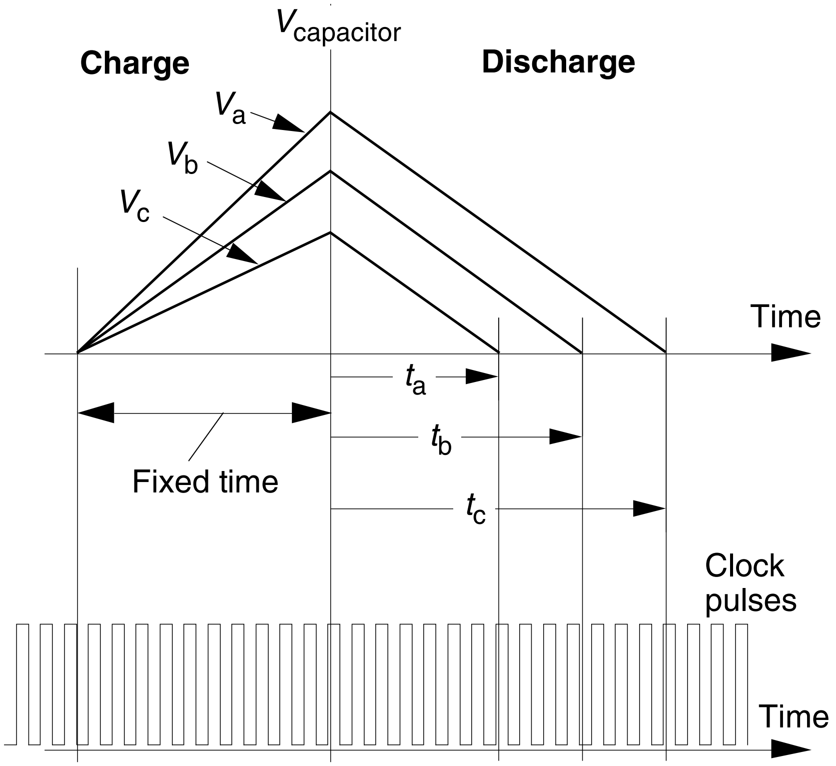


Figure 3.2 Schematic variation of the electrical resistance of a platinum resistance thermometer (PRT) and a thermistor. Figure 7.36 shows a more accurate representation of the electrical resistance of platinum. Notice that the resistance of a PRT increases gradually with increasing temperature. In contrast, the resistance of a thermistor falls dramatically as the temperature is increased.

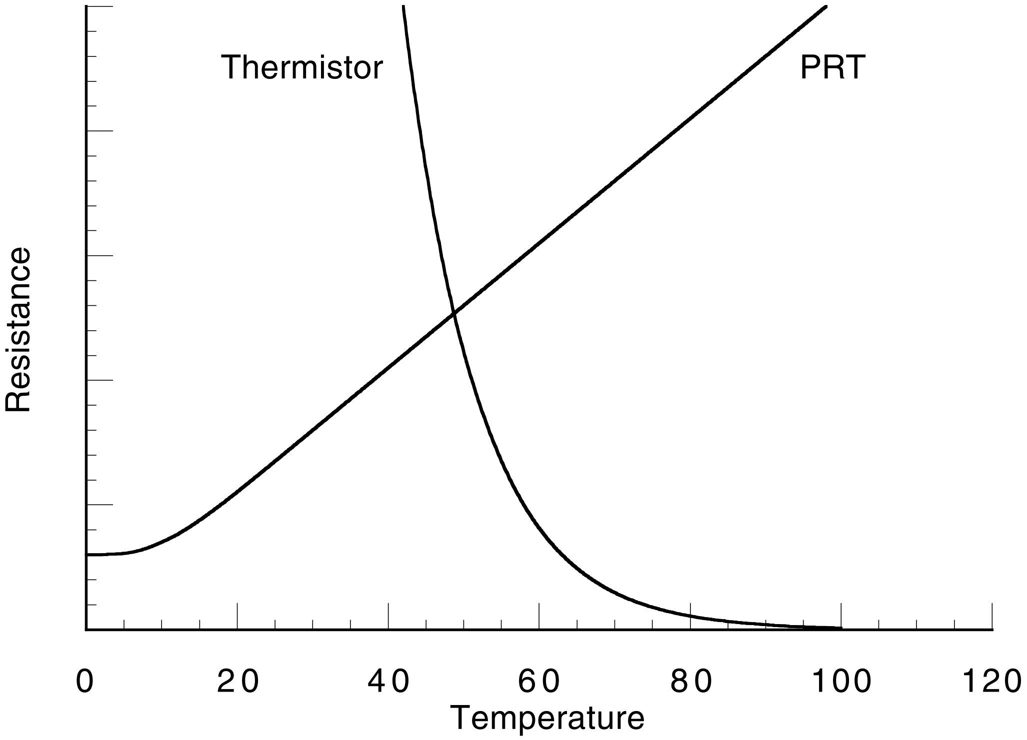


Figure 3.3. Illustration of the operation of a semiconductor diode thermometer. The variation of the voltage across the diode (a) is a non-linear, i.e. a non-ohmic function of the current through the diode. However if the current through the diode is fixed, the variation of the voltage with absolute temperature (b) is surprisingly linear over a wide temperature range.

(a)

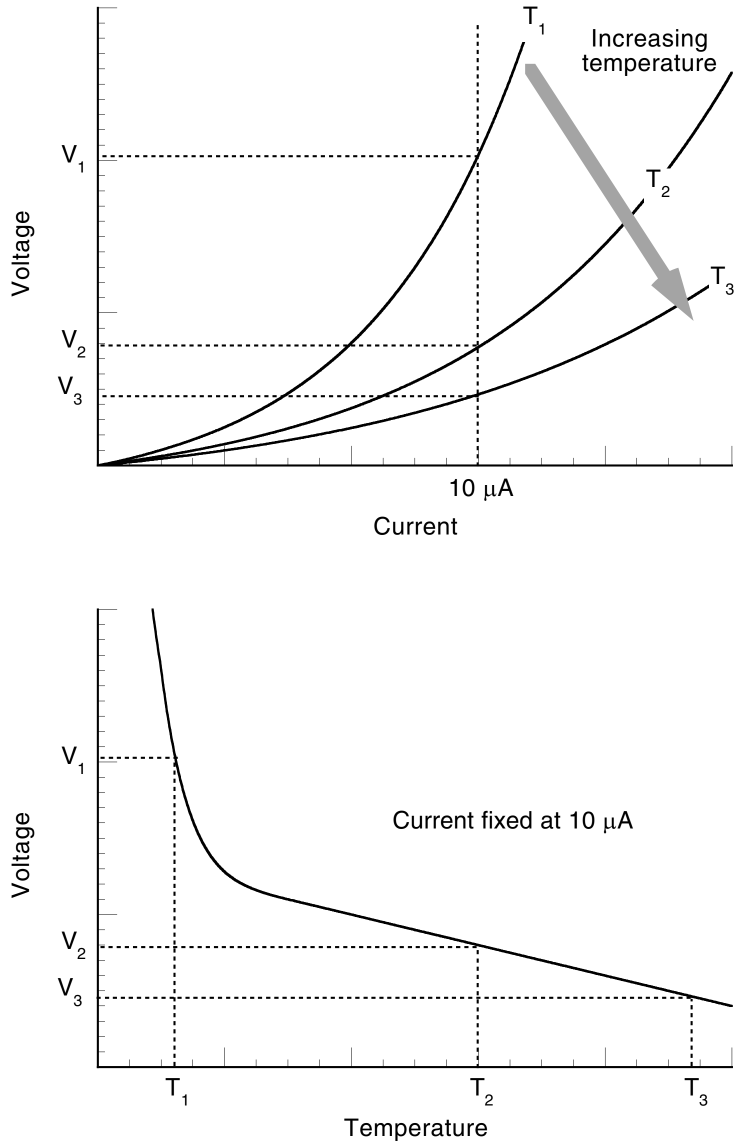


Figure 3.4 Illustration of a common configuration for the use of a thermocouple. The thermocouple junction is placed where the temperature needs to be measured, and the other ends of the wires are joined to copper wires in a reference bath held at a known, stable temperature (typically that of melting ice). The thermocouple voltage (typically 40 μV for each degree celsius difference between the junction temperature and the reference temperature) is measured by a high-resolution voltmeter or analogue to digital converter.

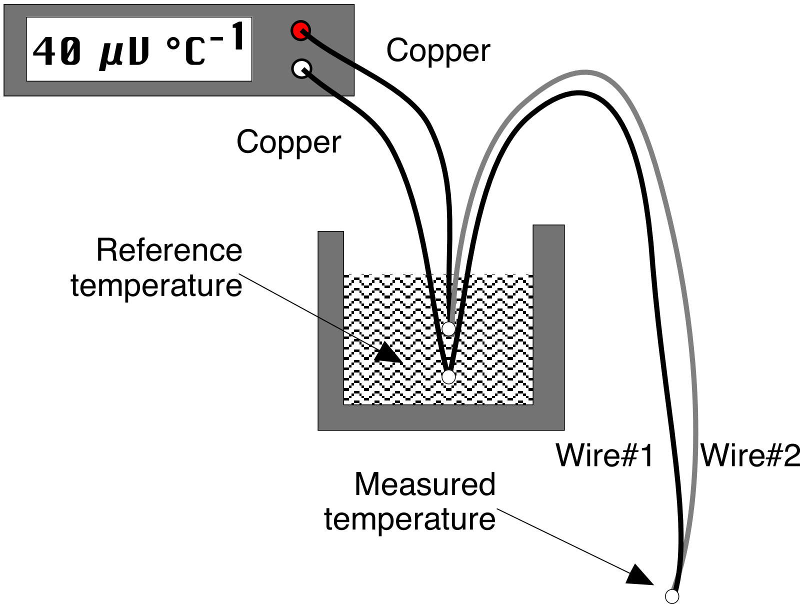


Figure 3.5 The principle of laser action.

(a) Consider a gas of atoms each of which has two quantum states which we can refer to as A and B.

(b) The relative proportions of atoms in the quantum states depends on their energies (E_A, E_B) and is given by a Boltzmann factor $\exp[-(E_B - E_A)/k_BT]$. This ensures that in equilibrium there are always more atoms in quantum state A (with lower energy) than quantum state B (with higher energy). When light of just the correct frequency $f = (E_B - E_A)/h$ is shone through the gas, transitions between quantum states are stimulated with equal probability in either direction. However, because there are many more atoms in quantum state A with lower energy, there are many more upward transitions (A ⇒ B) than downward transitions (B ⇒ A) so on average light is absorbed by the gas.

(c) In a laser, a non-equilibrium situation is arranged by one of many techniques in which there is a population inversion where many more atoms are in quantum state B with higher energy. Now the passage of light of just the correct frequency stimulates more downward than upward transitions and on average the medium emits more light at frequency f than initially entered the gas: Hence the name Light Amplification by the Stimulated Emission of Radiation

To create a population inversion it is in fact necessary that there be at least one other quantum state with energy greater than E_B, but I have not shown that state on these figures.

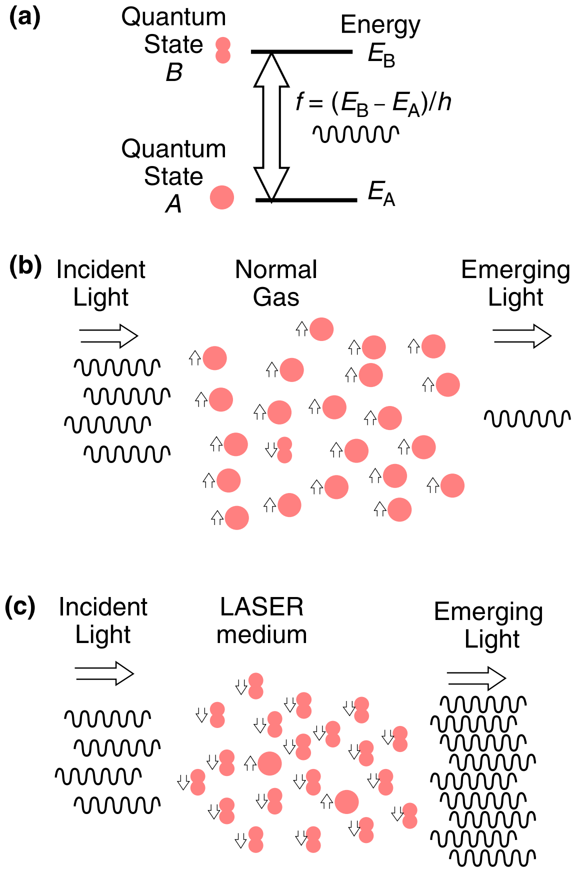


Figure 3.6 Light Transducers. Devices that generate a voltage or current when illuminated are technologically and experimentally important.

Photoresistors (a) are generally semiconducting substances in which extra carriers are created when illuminated with light whose photon energy exceeds its band gap. The extra carriers lower the electrical resistance of the substance. Although photoresistors are cheap, their change in resistance is not directly proportional to light intensity.

Photodiodes (b) are devices consisting of a junction of two semiconducting substances, most commonly p and n type silicon. When light is absorbed in the depletion layer between the p and n type silicon, a hole and an electron carrier are created and are drawn apart by the intense electric field in the depletion layer. Silicon photodiodes can measure light with wavelength s in the range 400 nm to 1050 nm. Although not equally sensitive to all wavelengths in this range, for any particular wavelength, the current is directly proportional to the light intensity. This is also the basic process used in silicon solar cells used to generate electricity from sunlight. See also Figure 7.56.

Photomultipliers (c) consist of a series of specially-coated electrodes inside a vacuum container. As explained in the text, a photon of light first liberates a few electrons at the first cathode. These electrons are then accelerated towards a second electrode where they release secondary electrons. These are then accelerated and after 7 or 8 electrodes, a detectable current pulse is produced in response to even a single photon.

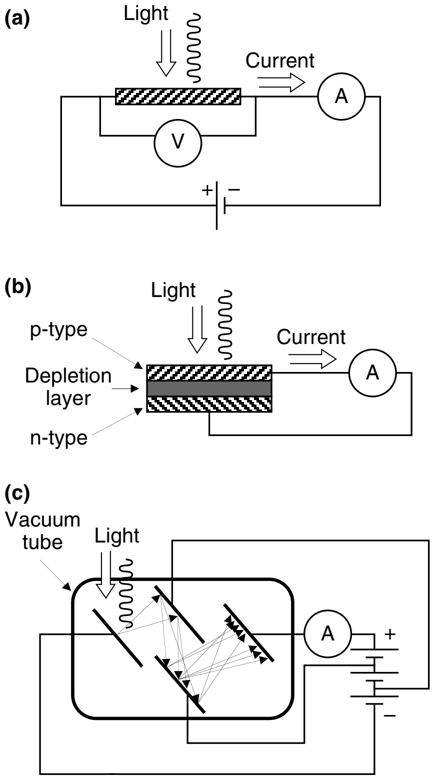


Figure 3.7 Illustration of the use of an optical interferometer. Experiments placed in either of the experimental regions can affect the interference of light from source S at detector D. To detect small movements an experiment could be arranged to move a mirror in the optical path. To detect changes in optical properties of a material, the material could be placed directly in the optical path

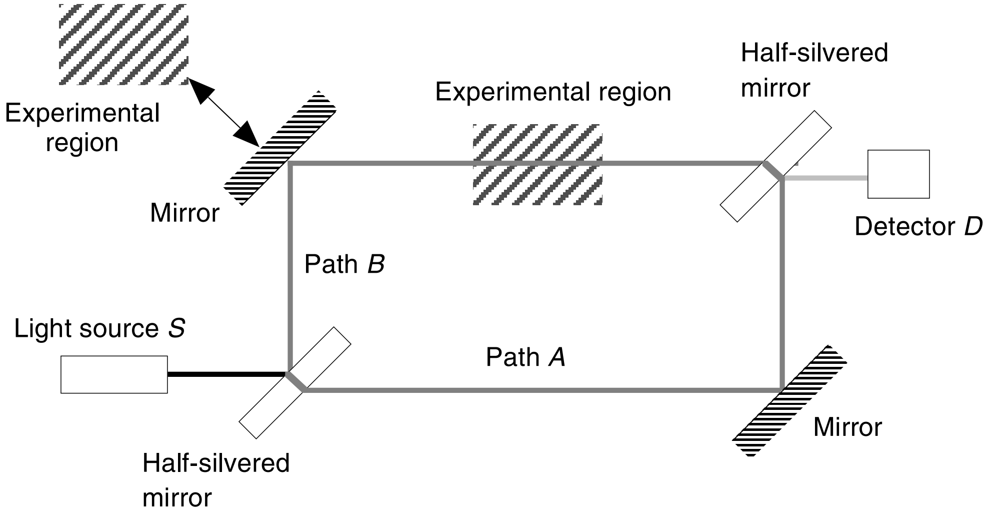


Figure 3.8 An optical interferometer used for the determination of change in height of a column of mercury.

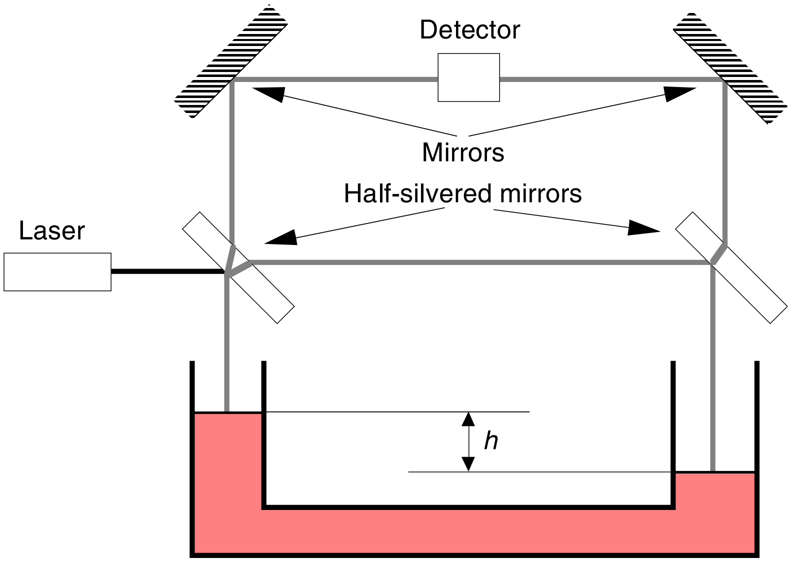


Figure 3.9 An optical interferometer used for the determination of the electrical polarisability of a gas. The apparatus is first set to a reference state by evacuating both the reference cell and the experimental cell. The reference cell is then kept under vacuum while the gas under investigation is introduced into the experimental cell. The light travelling through the experimental cell is then slowed down slightly by the interaction of its oscillating electric field with the electric charge on each atom. This results in a change in the intensity of light at the detector because the interference condition now depends on the transit time through the experimental cell.

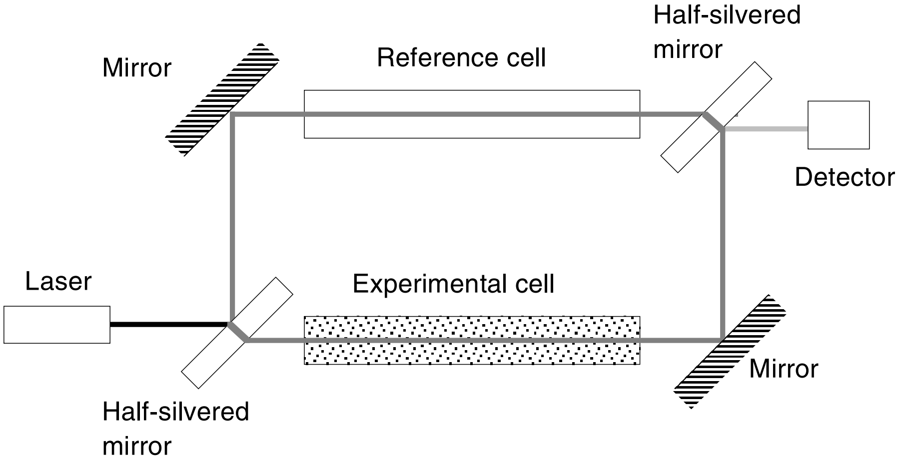


Figure 3.10 The Wheatstone Bridge circuit. A voltage source drives a current i_{bridge} through the resistance network illustrated. The detector V need not have, but most commonly will have, an impedance much greater than any of the other resistances in the circuit. The bridge is balanced when $R_a = R_b$ and $R_c = R_d$.

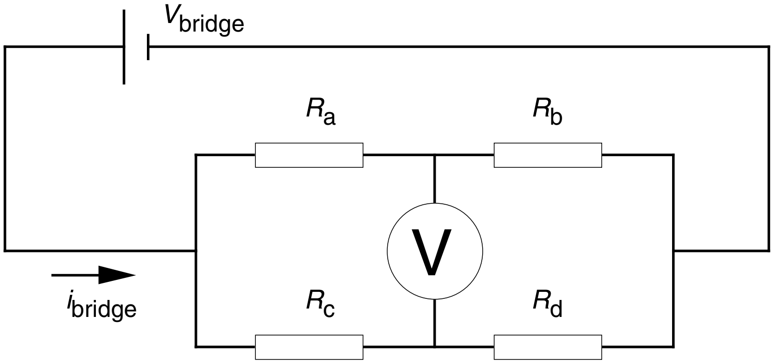


Figure 3.11. The alternative to a Wheatstone Bridge circuit. A voltage source drives a current i_{bridge} through the resistance R_{d}. The detector V must have an impedance much greater than R_{d}. If R_{d} changes by ΔR then the voltage across R_{d} changes by $\Delta V = i_{\mathrm{bridge}}\Delta R$.

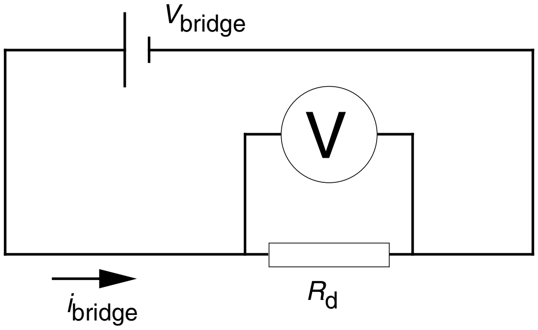


Figure 3.12 The Wheatstone bridge may be used to detect small changes in a resistance thermometer due to a temperature change ΔT.

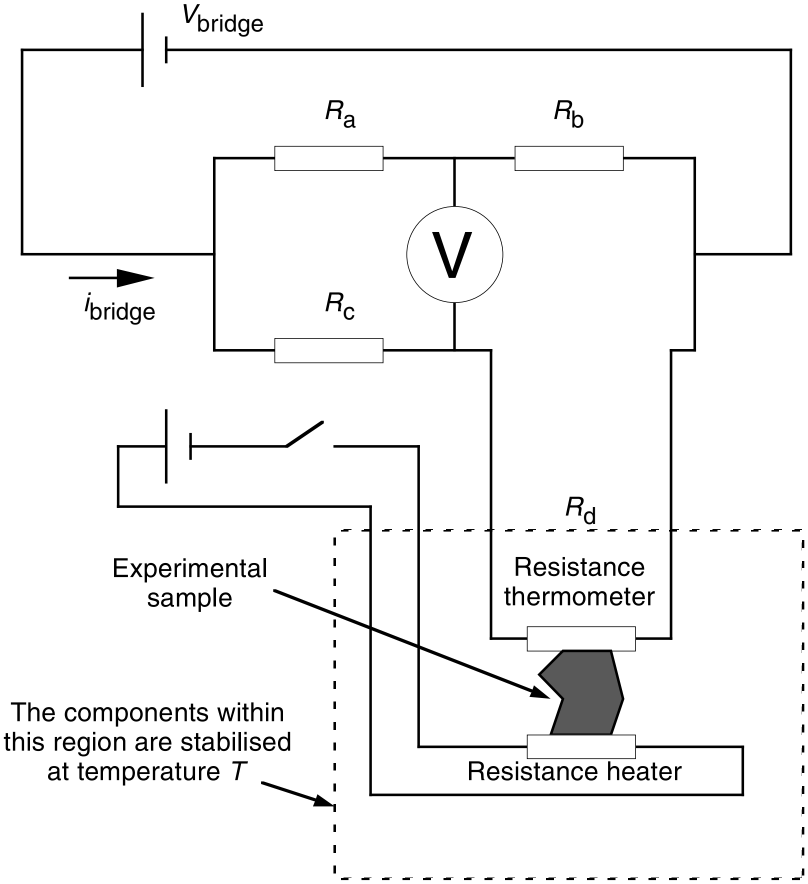


Figure 3.13 A schematic view of a capacitance cell. Small changes in the length of a sample cause changes in the separation between the two plates of a capacitor.

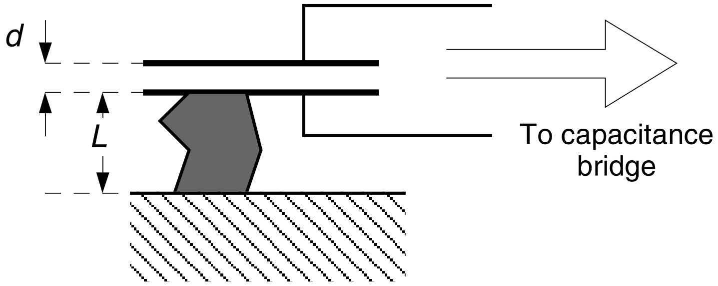


Figure 3.14 Example of the use of piston to create pressure environments. In (a) a force F acts over area A to produce a pressure $P_1 = F/A$. In (b) the force acts over a smaller area $A/4$ to produce a pressure $4P_1$, even though the force used is the same in both cases.

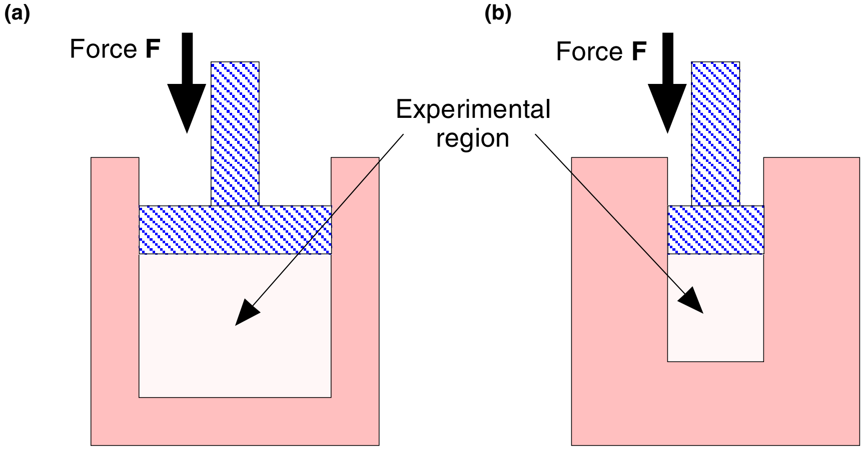
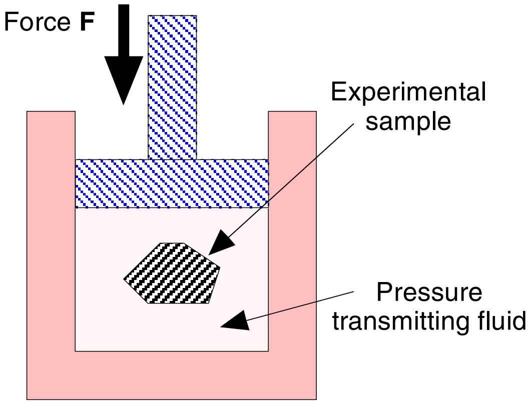


Figure 3.15 Illustration of techniques for applying high pressures to solid samples. The technique (a) uses a fluid around the sample to ensure that the pressure is transmitted hydrostatically. For application of the very highest pressures (b) the hardest material known, diamond, is used as a pressure anvil. The transparency of diamond allows relatively easy optical access. However the expense of large unflawed diamonds limits the size of the apparatus illustrated in (b), and all such experiments represent a considerable challenge to the experimenter.

(a)



(b)

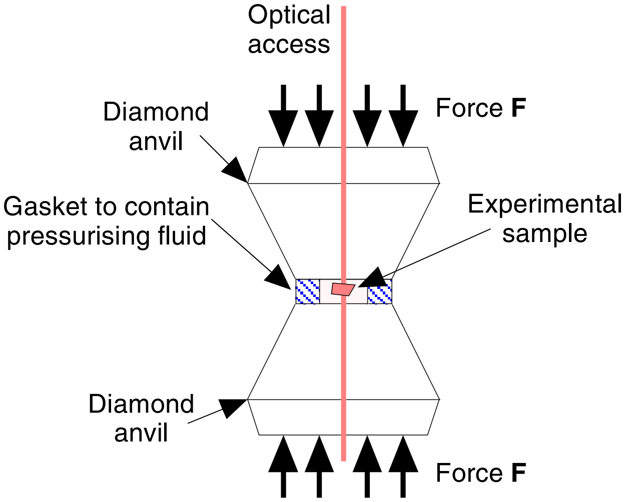
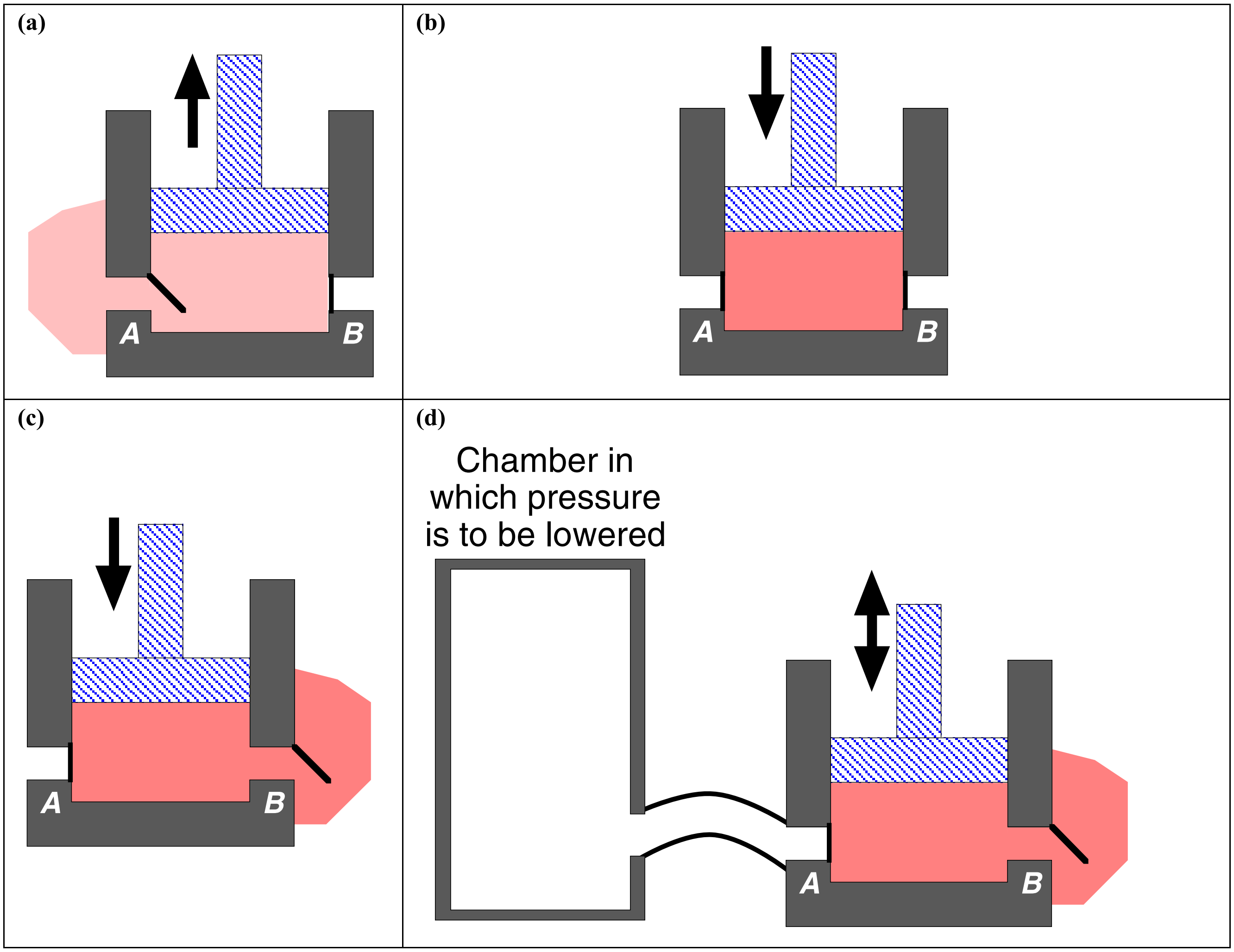
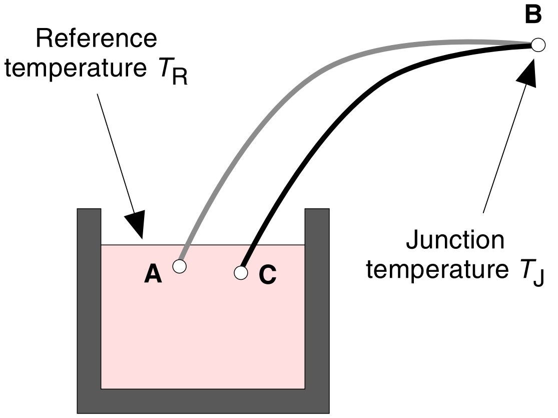


Figure 3.16 Illustration of the principle of operation of a mechanical vacuum pump. In (a) a piston/chamber is enlarged and ‘sucks in’ gas through *A* from the region in which the pressure is to be lowered. In (b) the connection *A* to the area in which the pressure is to be lowered is closed, and the piston lowered to compress the gas until the pressure exceeds atmospheric pressure (c), when a valve *B* opens to permit the compressed gas to be expelled. This process (d) can be used to lower the pressure in an experimental enclosure. Note: Modern vacuum pumps usually operate on a rotational rather than a reciprocating cycle as shown in (a) to (d) and they rarely look anything like this diagram might intimate.



P6. We mentioned in §3.3 that the voltage generated by a thermocouple did not arise at the junction between the two dissimilar metals. Instead it arose all along the wires and depended on the product of the so-called *Seebeck* coefficient $S(x)$ for a material and the temperature *gradient* dT/dx at each point on the wire.



In the figure above, points A and C are at the same reference temperature T_R and point B is the measurement junction with temperature T_J. A is connected to B by wire with Seebeck coefficient S_1 and C is connected to B by wire with Seebeck coefficient S_2. The voltage V_{AC} is given by:

$$V_{AC} = \int_A^C S(x)\frac{dT}{dx}\,dx$$

Show that if the Seebeck coefficients are constant along each type of wire, that V_{AC} is indeed proportional to the temperature difference between T_R and T_J and given by:

$$V_{AC} = \left[T_R - T_J\right] \times \left[S_2 - S_1\right]$$