

CHAPTER 9

Figures

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Figure 9.1 Histogram of the ratio of the density in the liquid phase at the melting temperature to the density in the solid phase of elements at 25 °C. The data is for 45 elements, of which 41 expand and 4 contract as they enter the liquid phase.

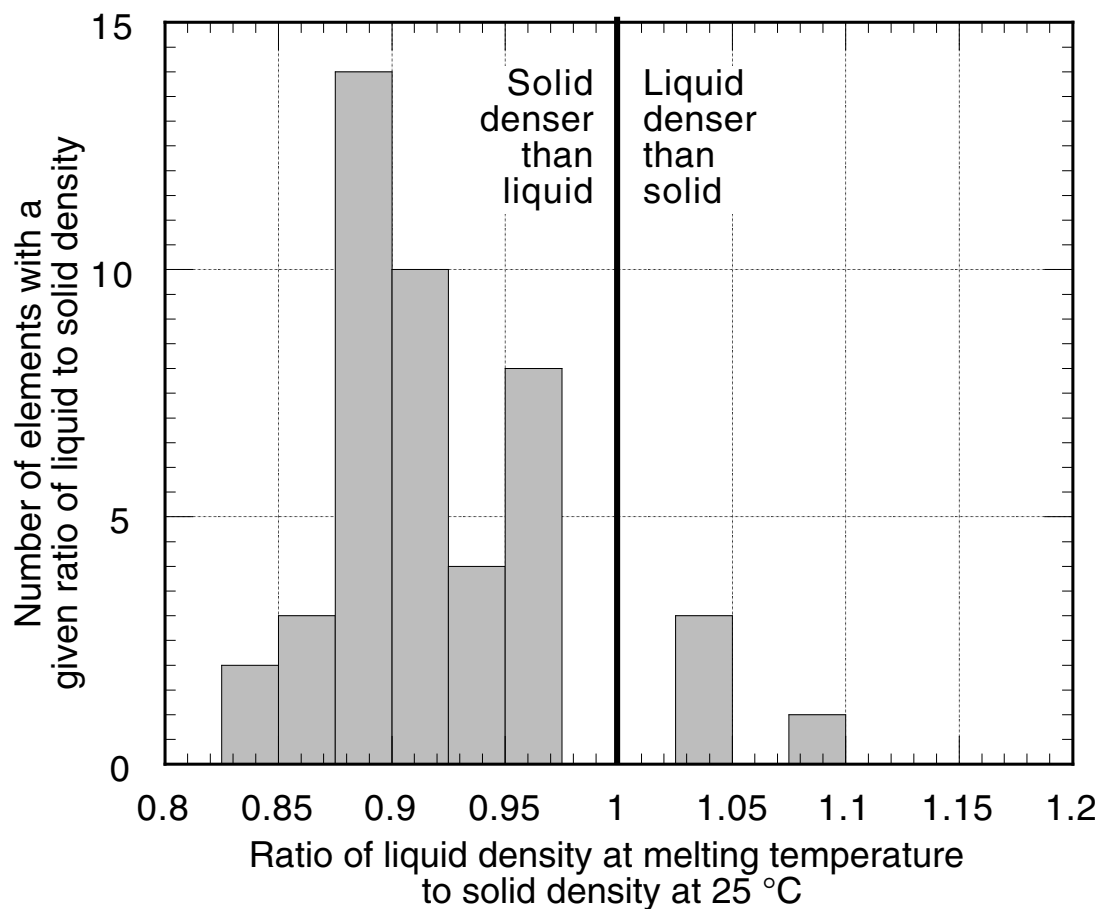


Figure 9.2 A graph of selected data from Table 9.2 showing the density of liquids with an OH group known as *alcohols* as a function of the relative molecular mass of the molecules.

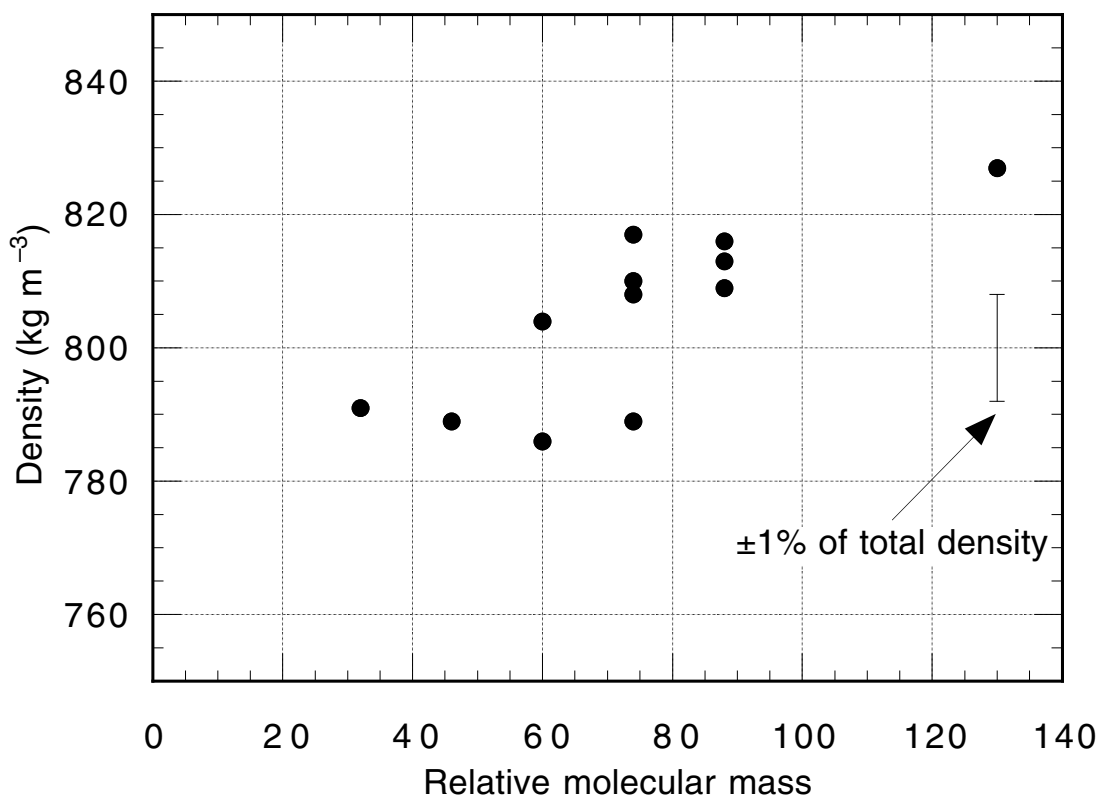
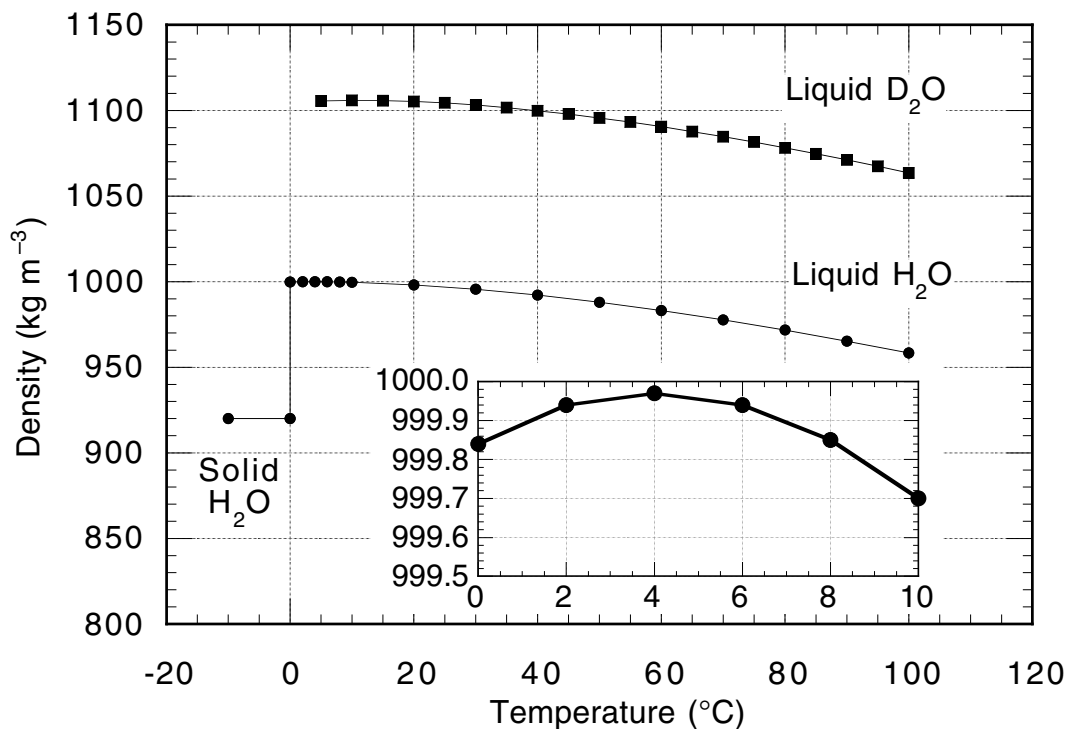


Figure 9.3 The density of water (H_2O) and heavy water (D_2O) as a function of temperature at atmospheric pressure. Data points plotted below 0°C refer to the density of ice. The inset shows the density of water between 0°C and 10°C showing the weak maximum in density at 3.98°C .



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Figure 9.4 The density of mercury in its liquid state plotted as a function of temperature. Notice the linearity and large magnitude of the thermal expansion: the density changes by about 7%.

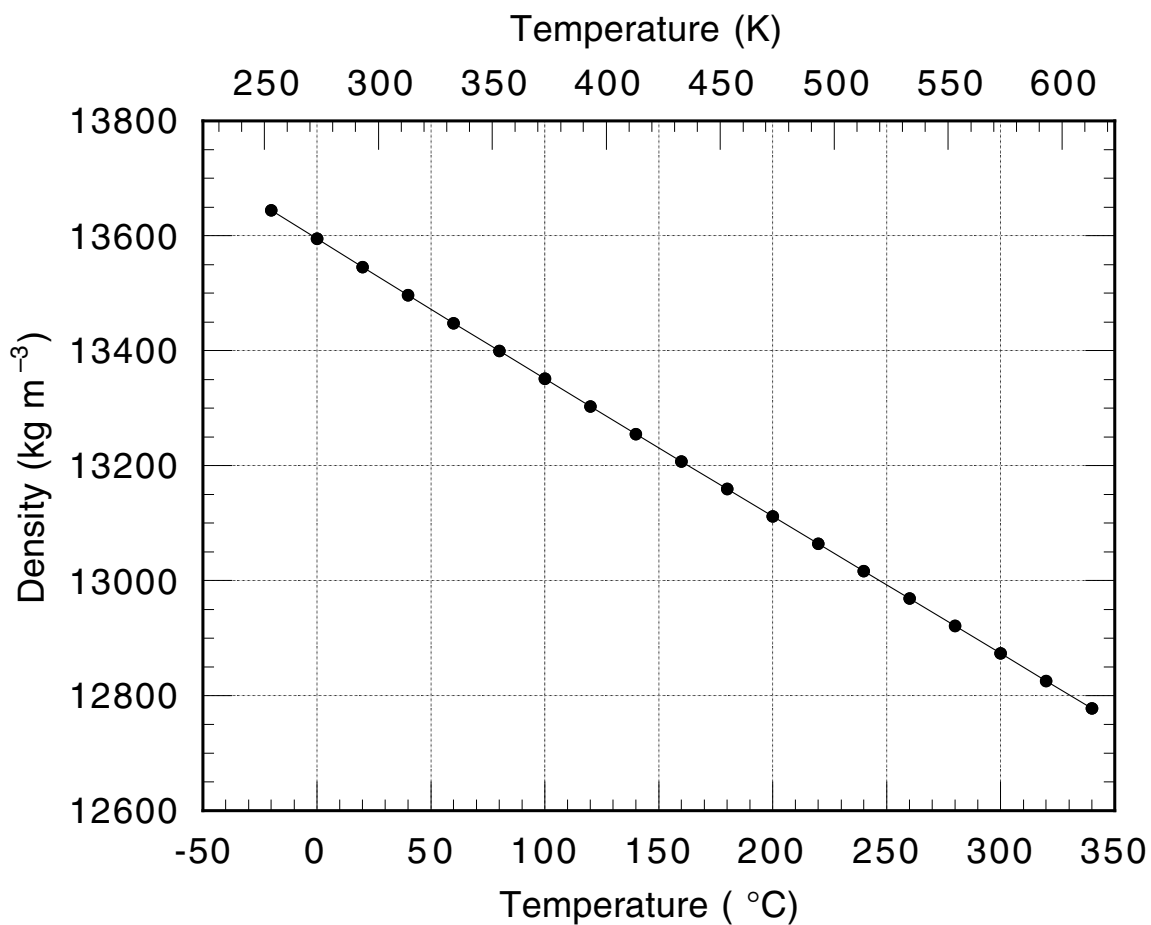


Figure 9.5 The figure may be used to calculate the ‘area density’ of close-packed two-dimensional circles that are analogous to a two-dimensional solid. The curved area is the same in this figure as in Figure 9.6 and contains the centres of 136 circles. The curved area is chosen to avoid counting bias near the edge of the area.

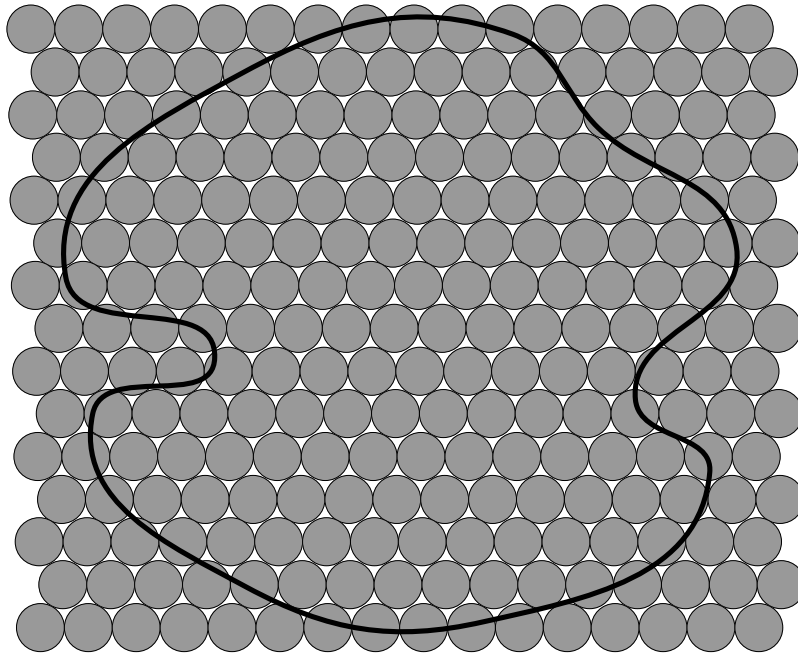


Figure 9.6 The figure may be used to calculate the ‘area density’ of close-packed two-dimensional circles that are analogous to a two-dimensional liquid. The curved area is the same in this figure as in Figure 9.5 and contains the centres of 126 circles.

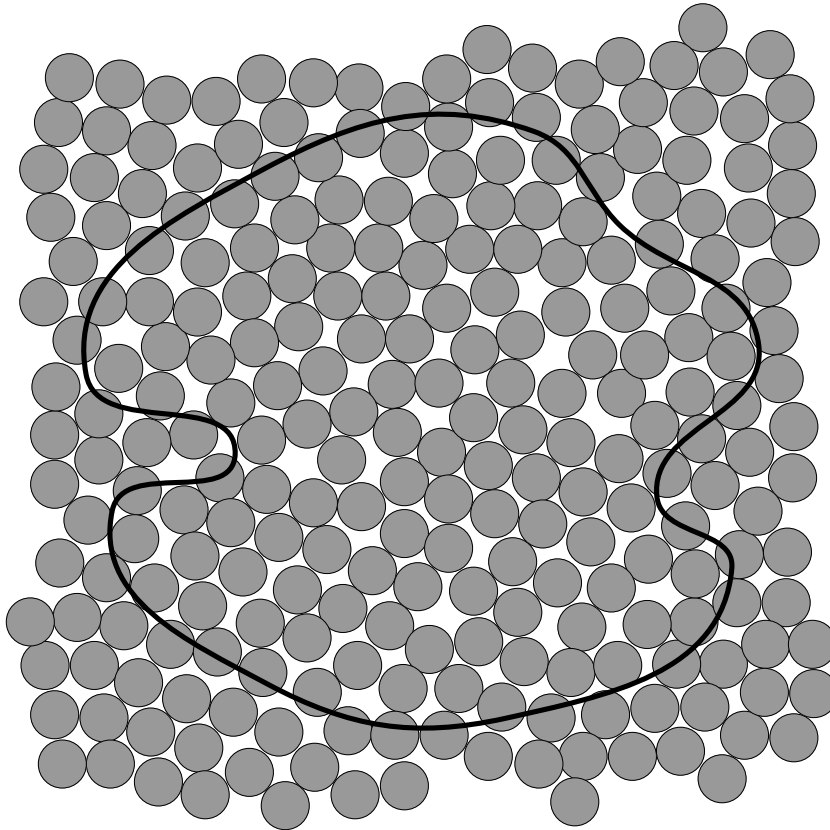
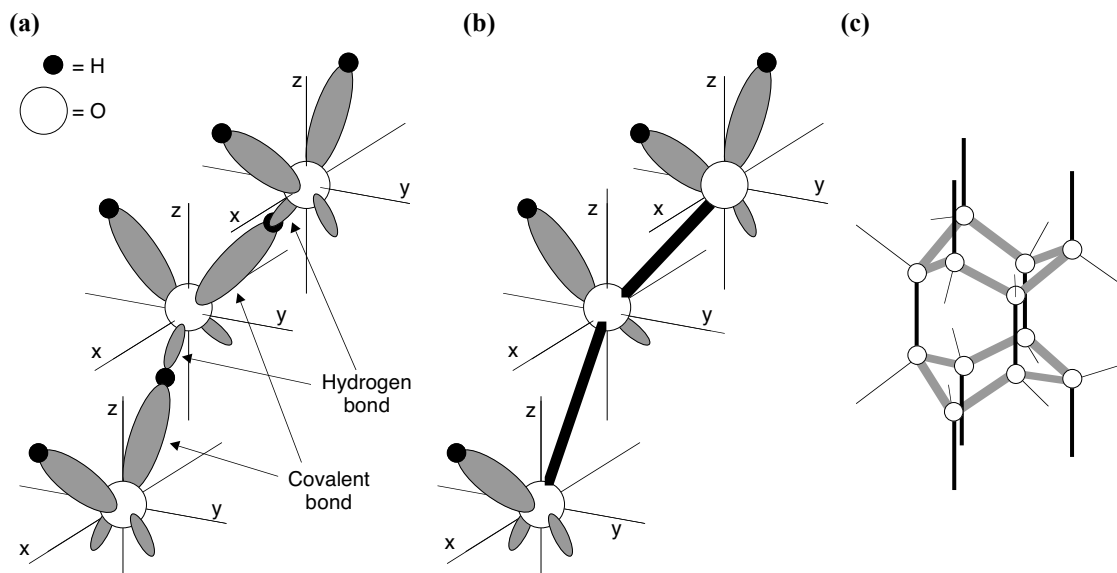


Figure 9.7 Qualitative indication of the structure of ice. (a) A central water molecule linked to two others. Concentrating on the oxygen atoms, we can see that each oxygen can link to four other oxygen atoms arranged roughly tetrahedrally around it. Two of these links are of the form **O=covalent bond=H=hydrogen bond=O** and two are of the form **O=hydrogen bond=H=covalent bond=O**. (Notice the change in order of the covalent and hydrogen bonds.) One example of each form of O=O linkage is shown as a straight line in (b). In (c) the structure of ice is indicated with the circles representing only the oxygen atoms and the lines representing either of the two types of O=O linkages discussed. Different bonds have been drawn either as thin, bold or shaded lines to emphasise the structure. In fact all the bonds are equivalent.



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Figure 9.8 Detailed view of the thermal expansivity anomaly in water. Notice the tiny scale of the anomaly.

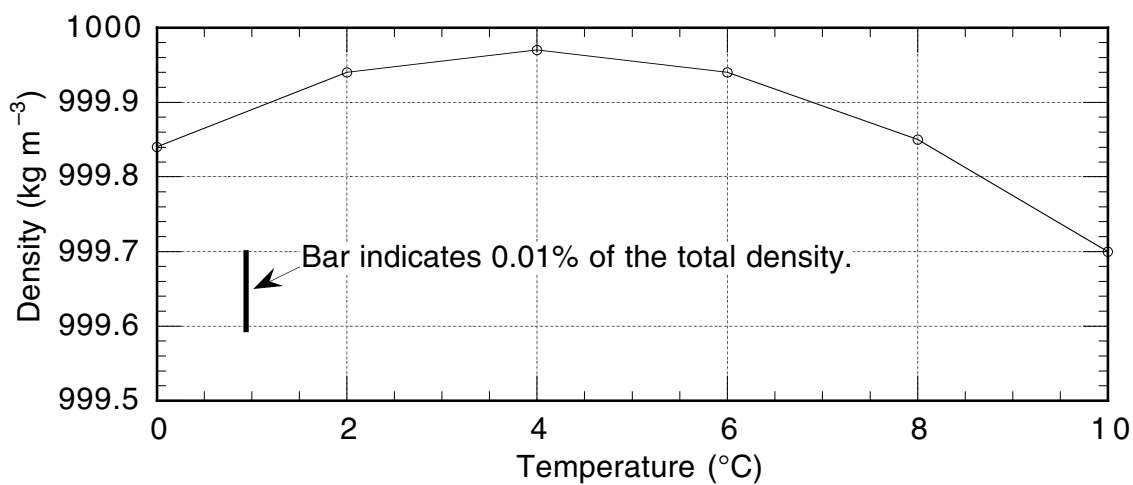
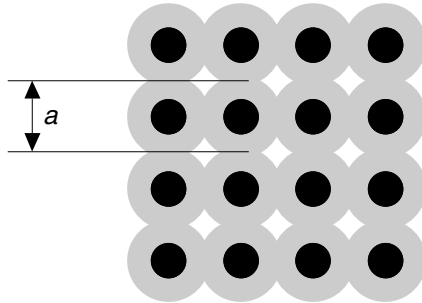


Figure 9.9 A molecule has more space available to it the liquid state than the solid state. We imagine that the molecules move freely as in a gas across the extra space Δa within the liquid state.

Solid



Liquid

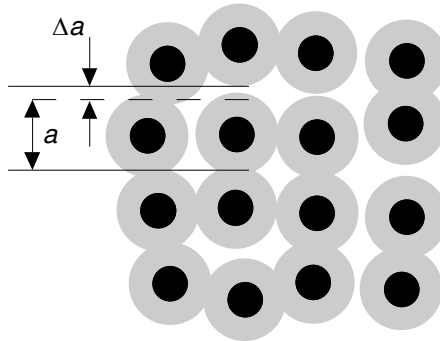


Figure 9.10 (a) Cross-section through a liquid showing that when a plate is drawn through a liquid it drags with it layers of liquid. This corresponds to a transfer of z -momentum in the x -direction. The viscosity is a measure of the amount of z -momentum transferred. (b) Two plates, one fixed to a wall via a spring and one free to move. When the top plate is moved, the lower plate experiences a force which depends on the speed v of the first plate, and the distance x (Equation 9.17). (c) The viscosity of liquids can be more easily determined by measuring the damping of torsional oscillations of circular plates.

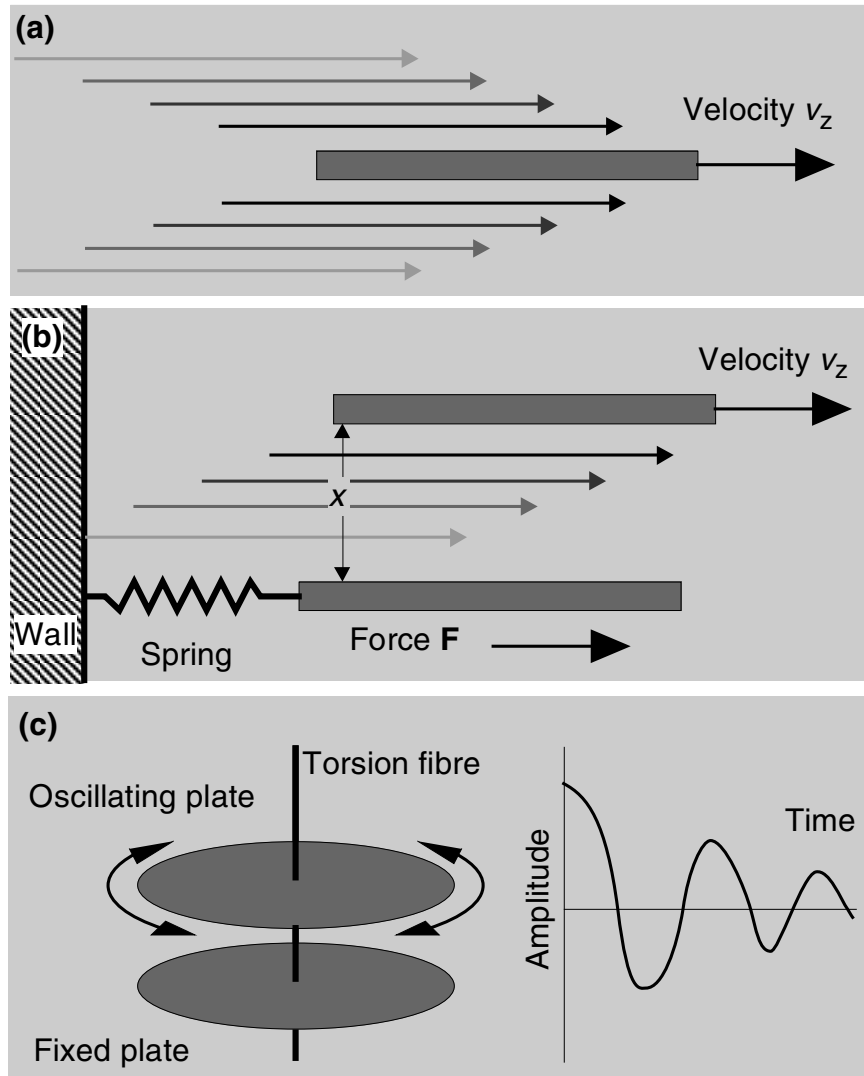


Figure 9.11 The viscosity η (Pa s) of various substances from Table 9.6 plotted as a function of the temperature. Note that the vertical scale is logarithmic covering three orders of magnitude.

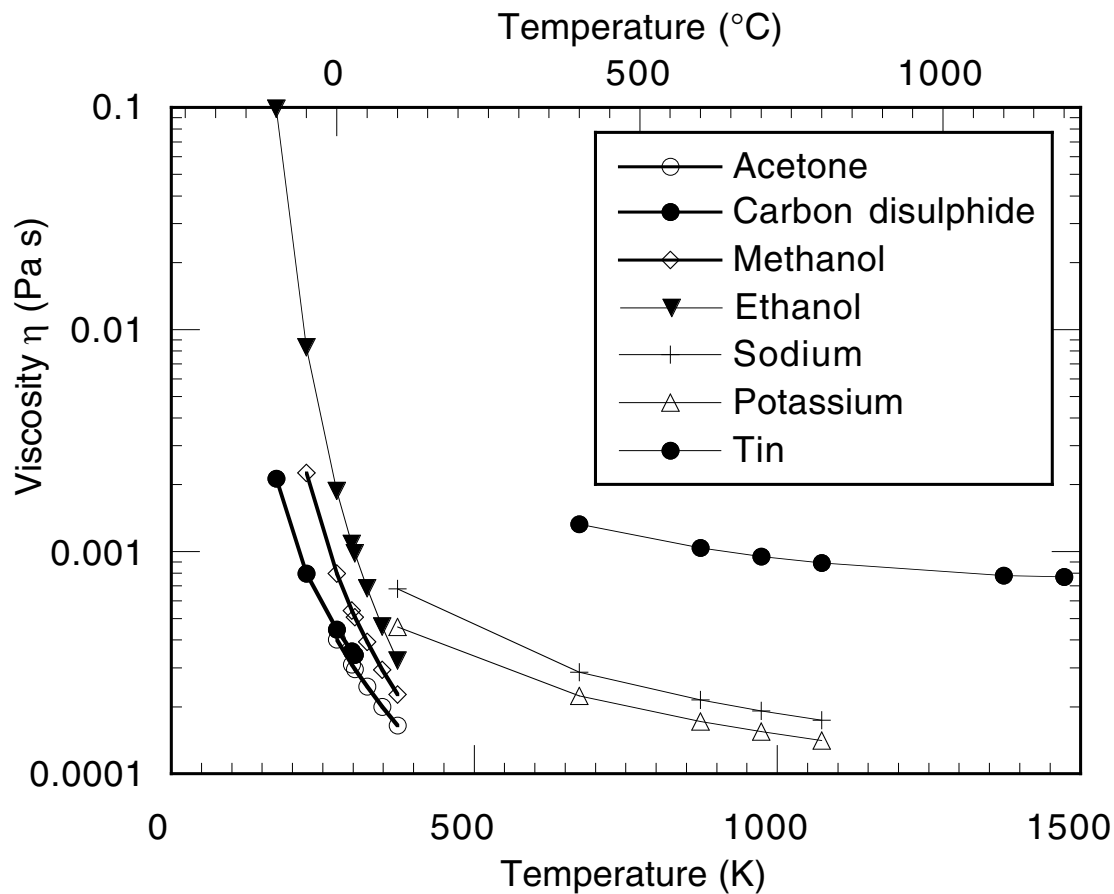


Figure 9.12 The viscosity η (Pa s) of water plotted as a function of the temperature. Note that the vertical scale is linear.

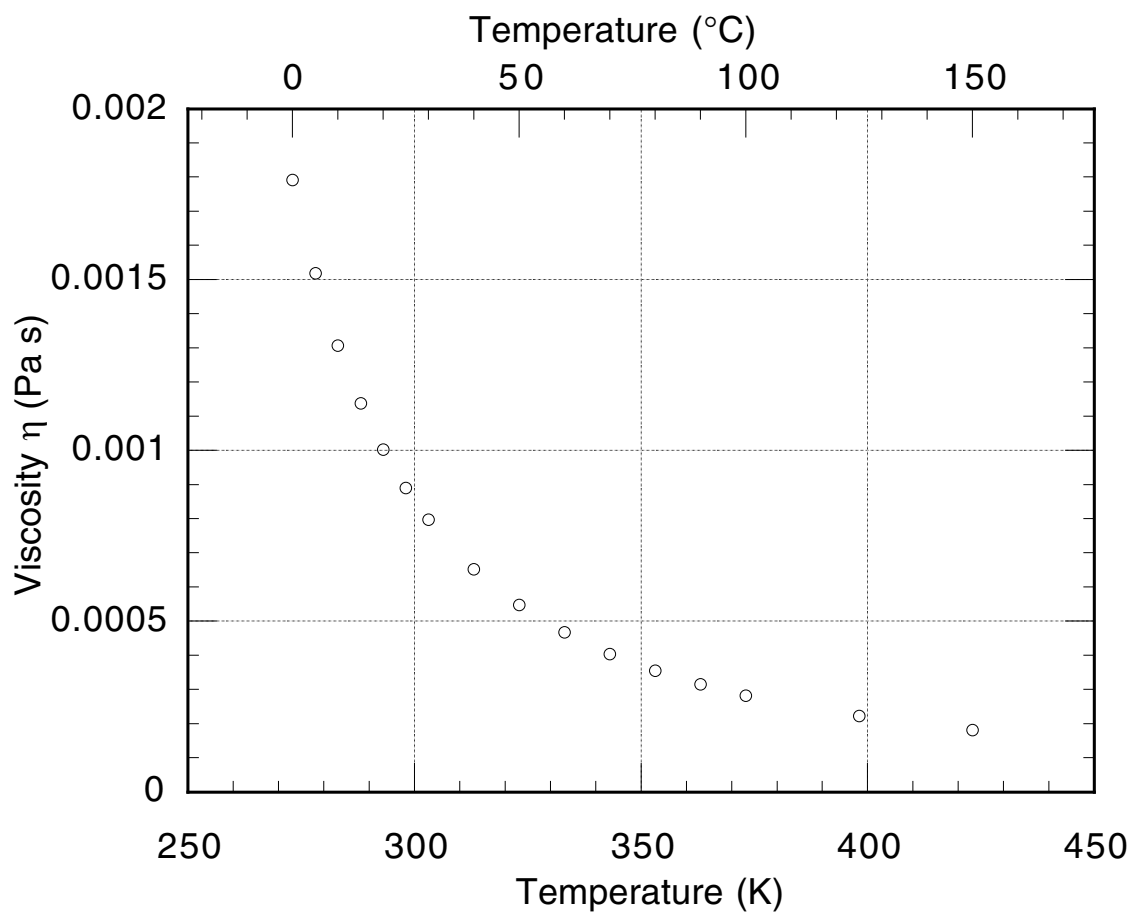


Figure 9.13 The viscosity η (Pa s) of various substances from Table 9.6 plotted on a logarithmic axis as a function of inverse temperature. Note that the vertical scale covers three orders of magnitude in viscosity. The lines are fits to the data points, with slopes indicated in Table 9.8.

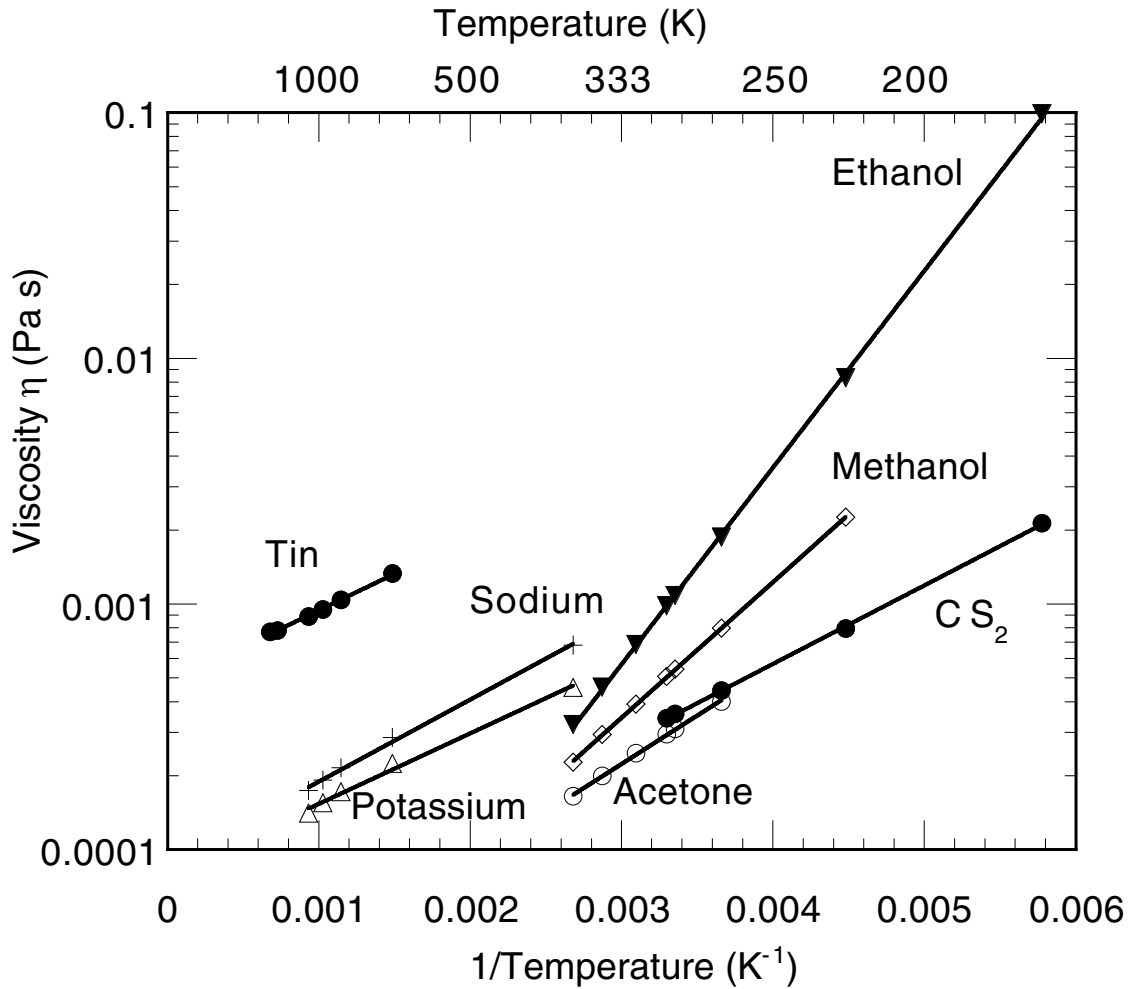


Figure 9.14 The viscosity η (Pa s) of water plotted on a logarithmic axis as a function of the inverse temperature. The two filled circle (\bullet) data points are taken under pressure above 100 °C. The line is a fit to the data taken between 0 °C and 100 °C and has a slope of 1862 K. The data conform fairly closely to the line but clear signs of curvature are evident.

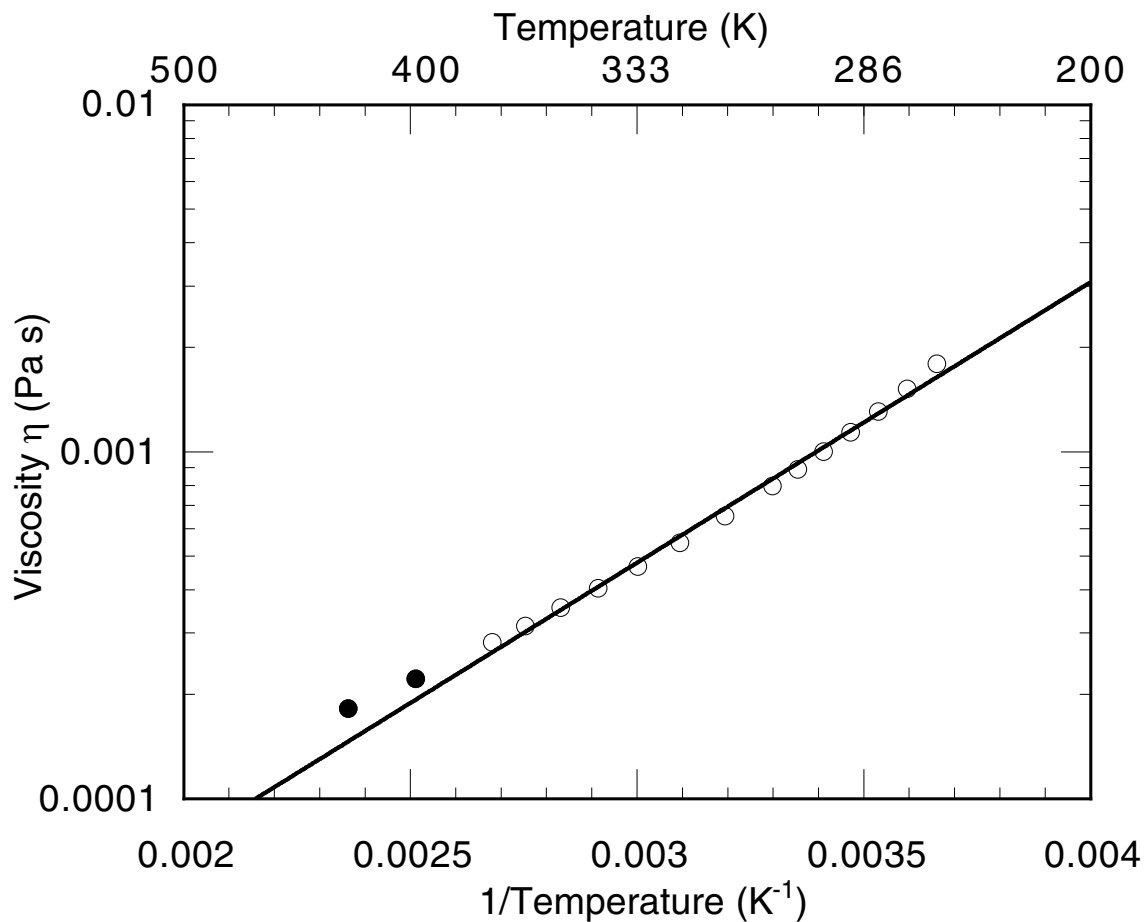


Figure 9.15 (a) A (hypothetical) liquid with no surface tension and (b) a real liquid showing the effect of surface tension.

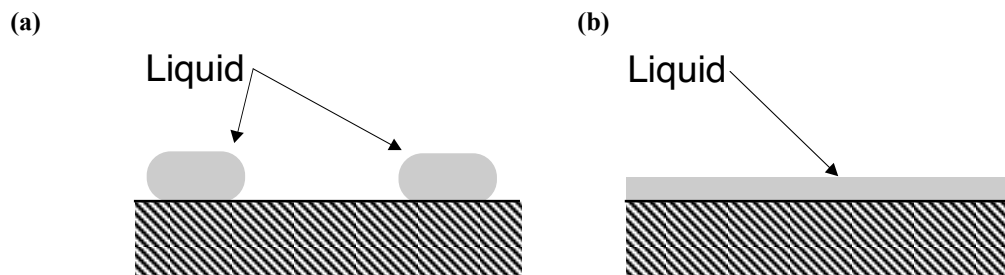


Figure 9.16 (a) A conceptually simple, but impractical, device for investigating the surface tension of liquids.

(b) Moving the arm by dx increases the area of a liquid film by $2Ldx$. The factor of 2 arises because new surface area is created on both the upper and lower surfaces.

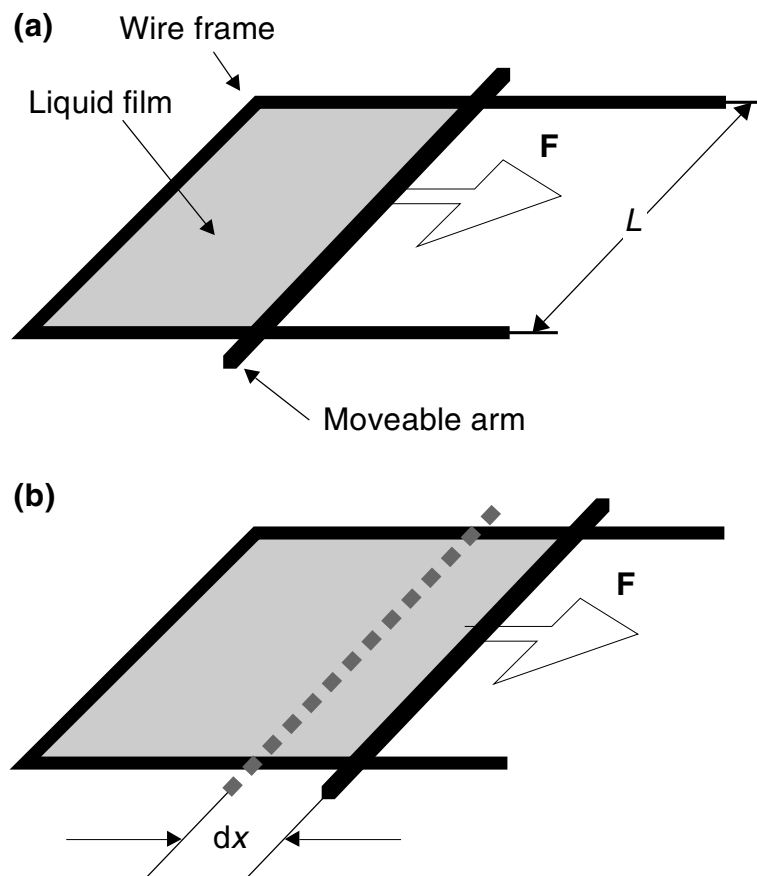
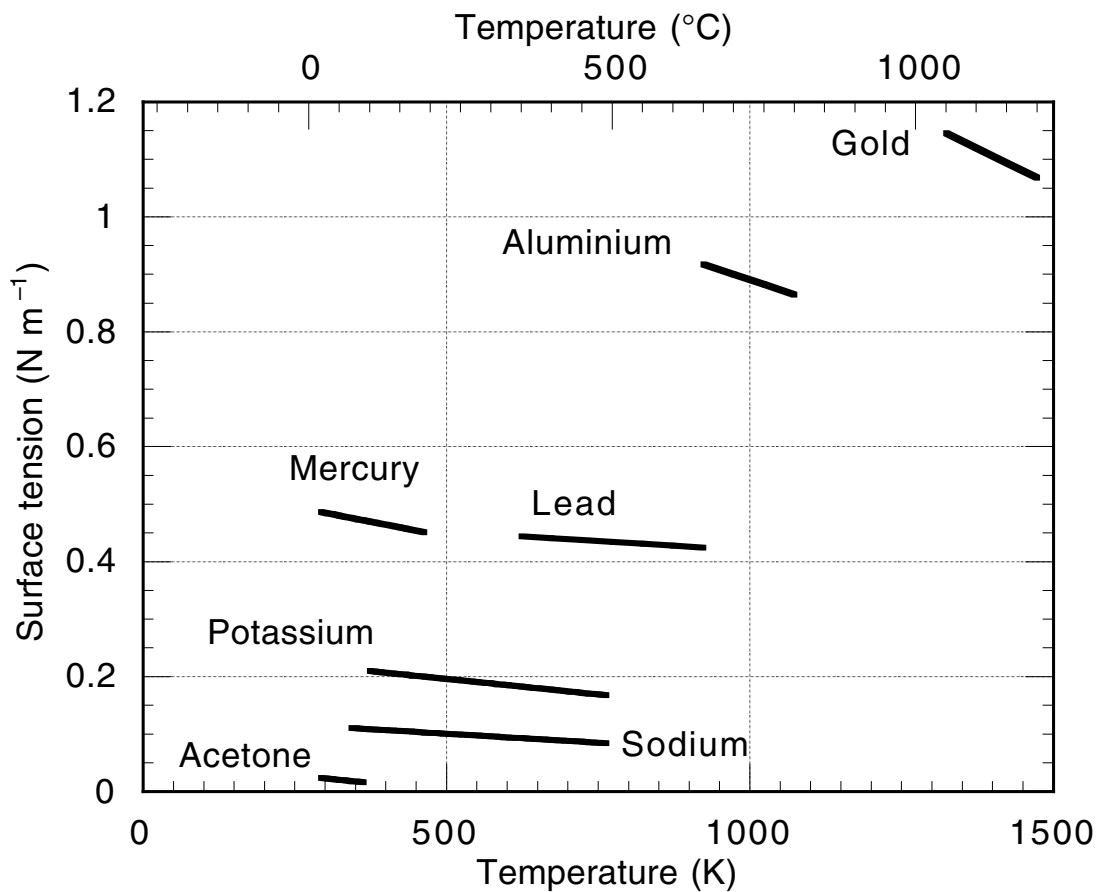


Figure 9.17 The surface energy or surface tension of various substances from Table 9.8 in units of mN m^{-1} s as a function of temperature. Notice the large difference in scale between this figure and Figure 9.18.



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Figure 9.18 The surface energy or surface tension of water in units of N m^{-1} s as a function of temperature. Notice the large difference in scale between this figure and Figure 9.17.

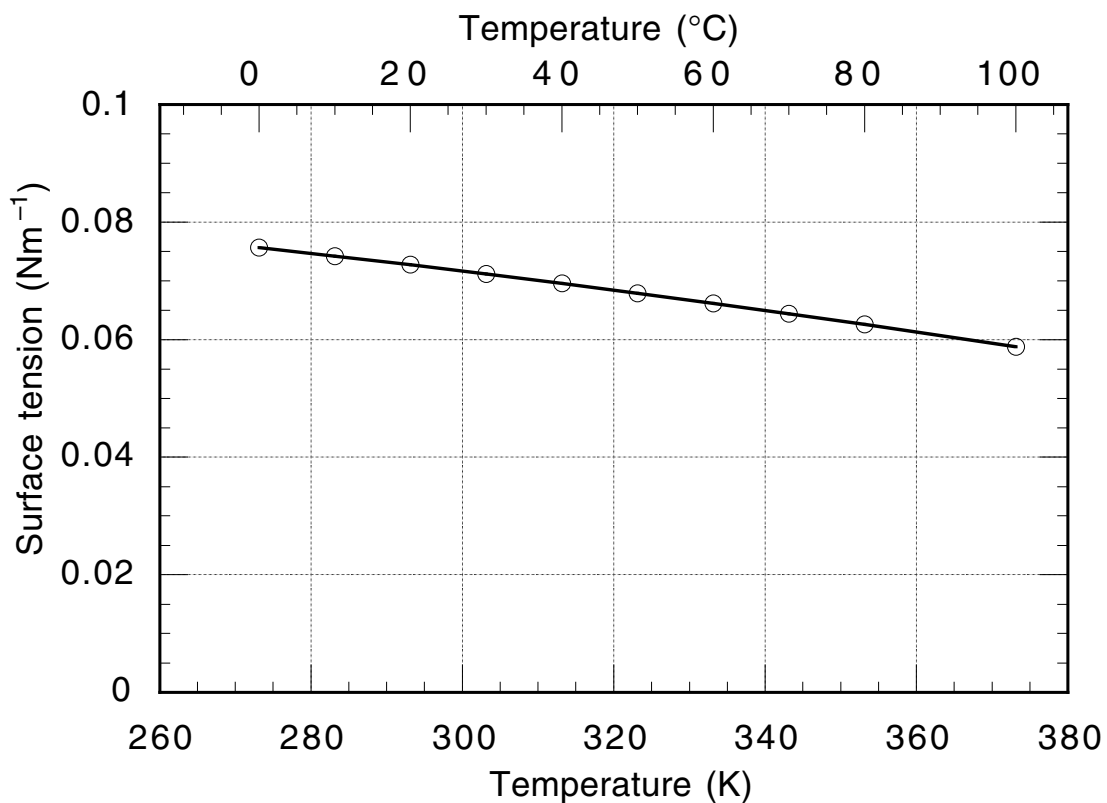


Figure 9.19 A two-dimensional illustration of the situation of molecules near the surface of a liquid. In three-dimensions, molecules such as *A* still interact with roughly half as many molecules as a molecule within the liquid such as *B*.

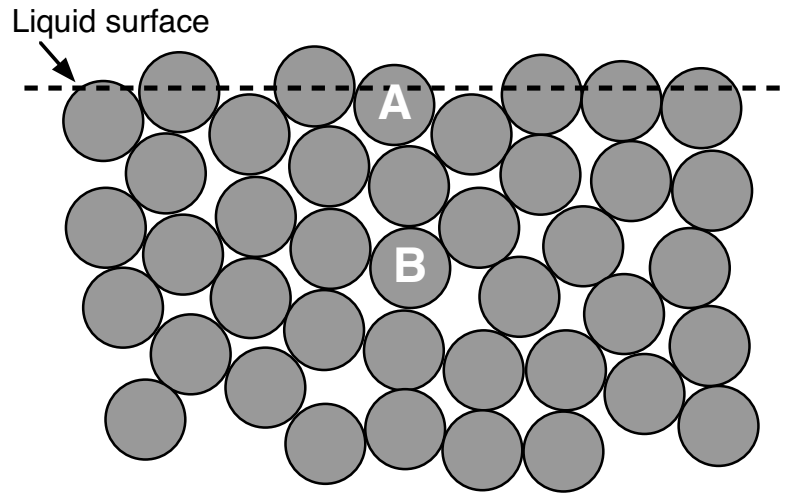


Figure 9.20 A view looking down on the surface of the liquid. In order to estimate the surface energy, we need to count how many molecules (such as A) there are per unit area. Roughly speaking the answer will be $\approx 1/a^2$.

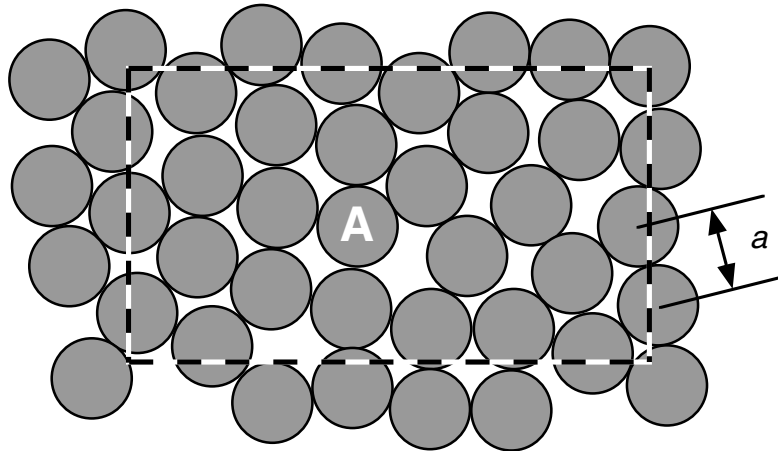
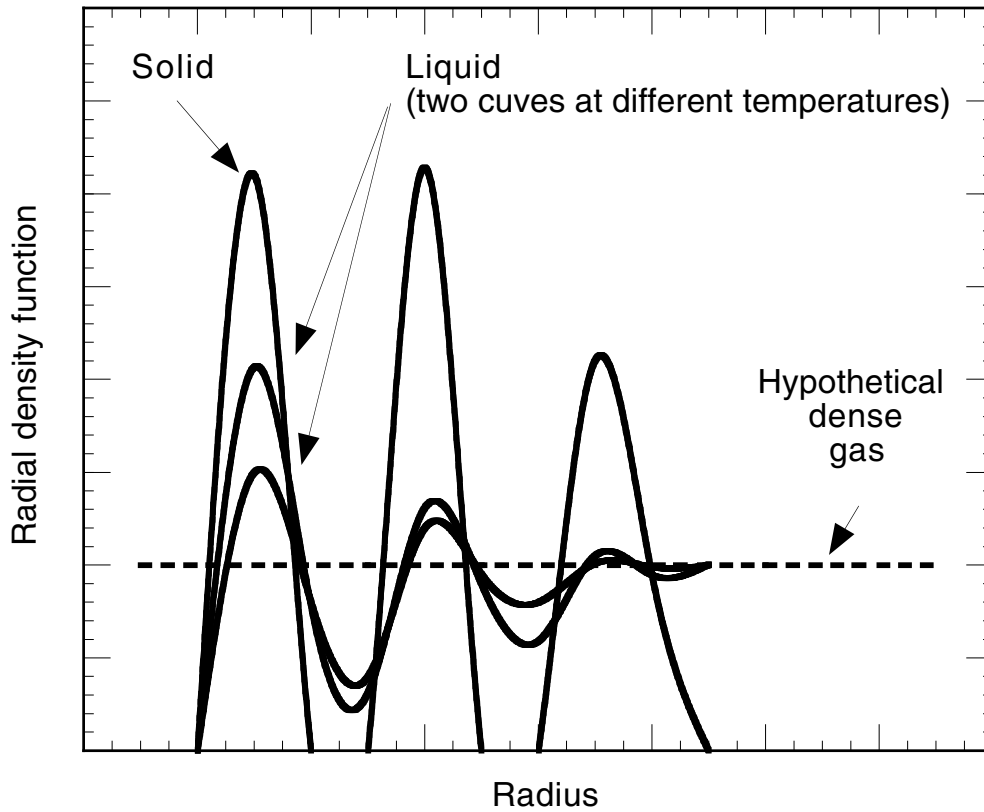


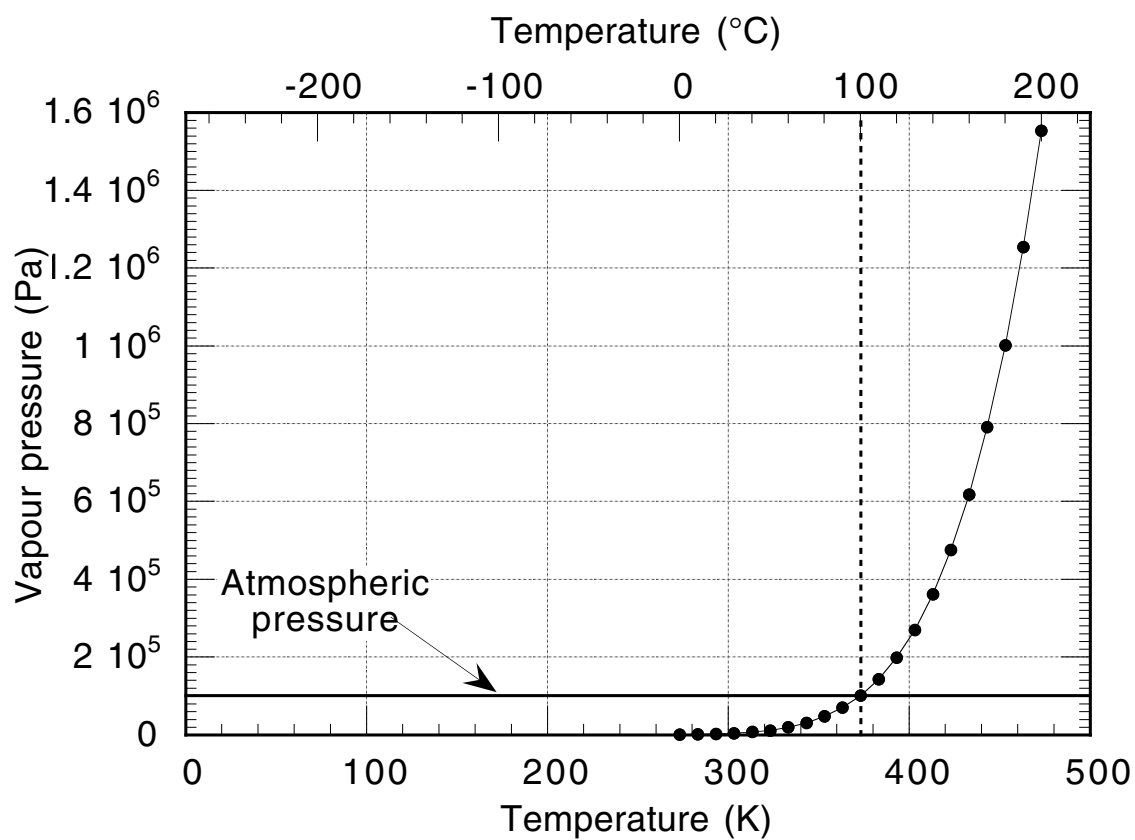
Figure 9.21 Schematic diagram of the radial density function $n(r)$ at different temperatures in the liquid phase. For comparison, the figure also shows the $n(r)$ of the solid and of a (hypothetical) gas-like state with the same average density as the liquid. At higher temperatures the correlations between molecular positions that gives rise to the peaks and troughs in the $n(r)$, are weakened. It can be seen that, while still maintaining the same average density, the *average* separation of molecules increases. This results in a reduction of the overall binding energy. This occurs because there is an increase in the probability of molecules being at the troughs of the function, and a decrease in the probability of them being at the peaks.



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Figure 9.22 The vapour pressure of water as a function of temperature plotted on (a) a linear scale and (b) a logarithmic scale. The boiling temperature is defined as the temperature at which the vapour pressure equals atmospheric pressure (0.10135 MPa), which for water occurs at 99.975 °C.

(a)



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Figure 9.22 The vapour pressure of water as a function of temperature plotted on (a) a linear scale and (b) a logarithmic scale. The boiling temperature is defined as the temperature at which the vapour pressure equals atmospheric pressure (0.10135 MPa), which for water occurs at 99.975 °C.

(b)

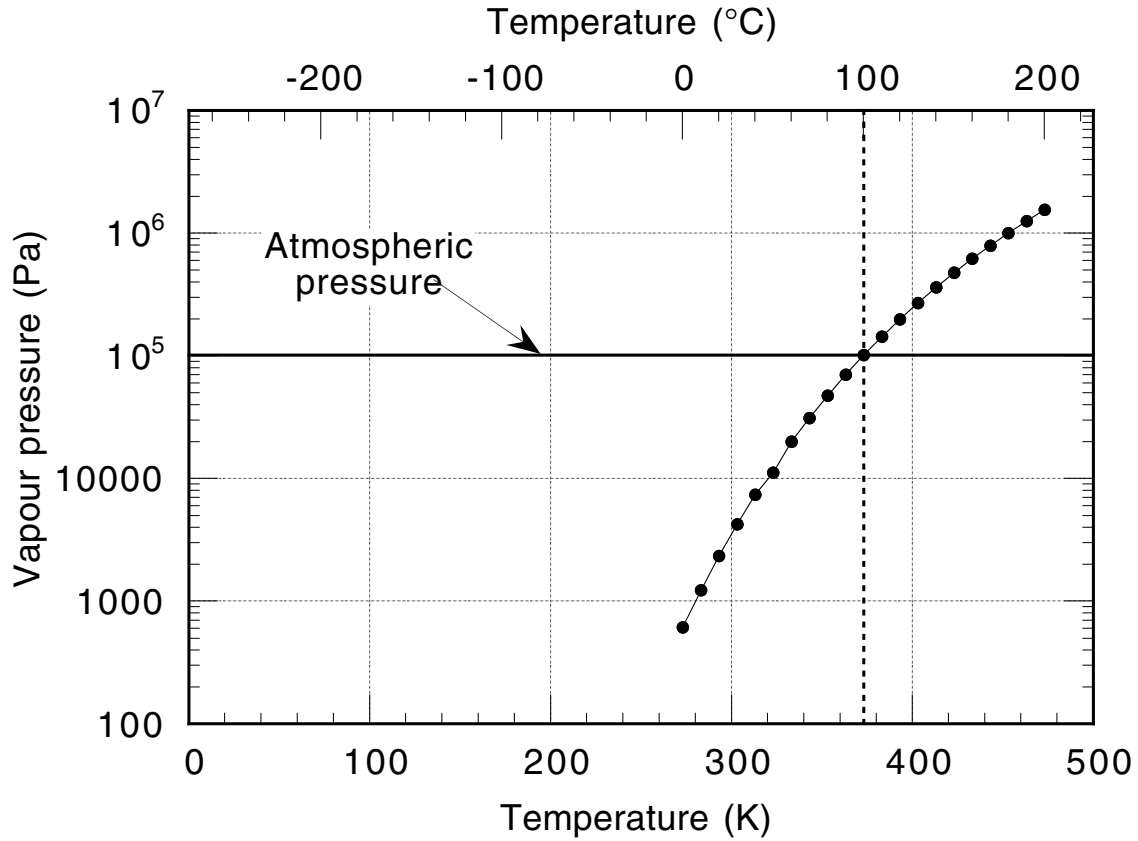
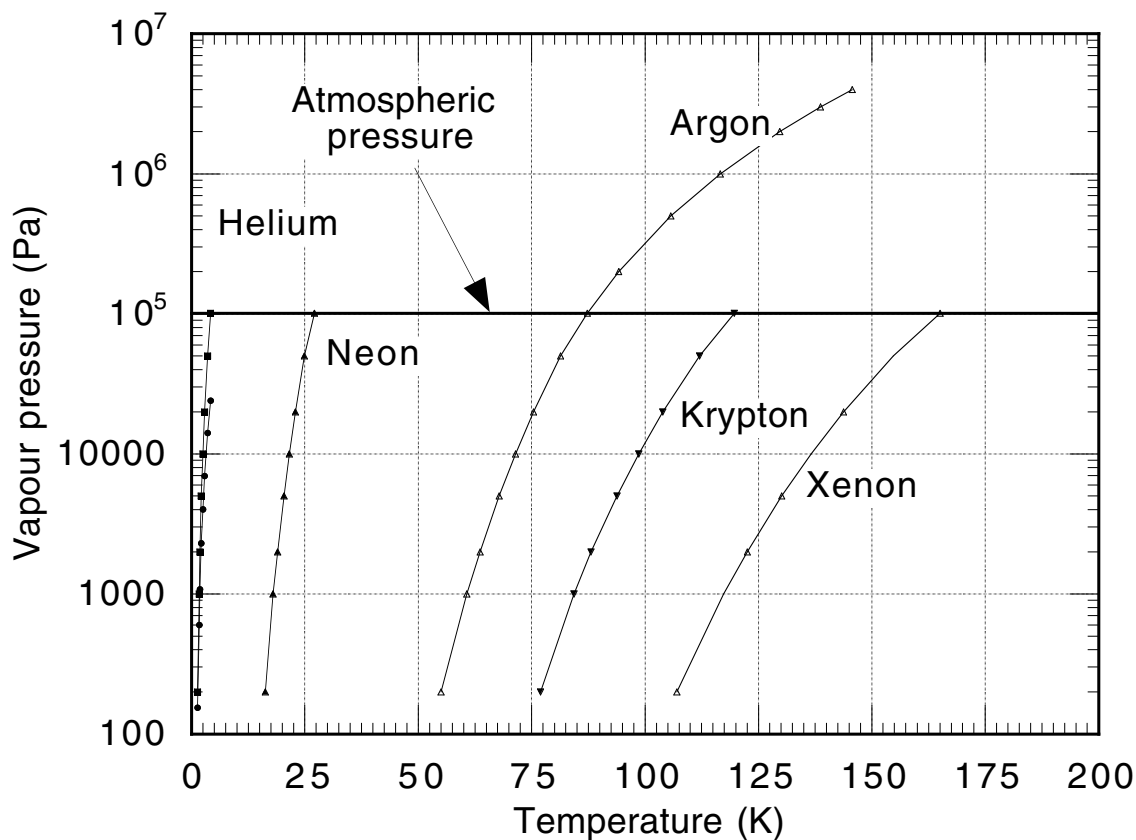


Figure 9.23 The vapour pressure of the rare gases as a function of temperature plotted on a logarithmic scale. The boiling temperature is defined as the temperature at which the vapour pressure equals atmospheric pressure (0.10135 MPa), which for these substances occurs at: He 4.22 K; Ne 27.1 K; Ar 87.3 K; Kr 119.8 K; Xe 165.1 K. Note: For much of the indicated range, most of these elements are solid, and the vapour co-exists with the solid rather than the liquid state. This is discussed further in Section 11.6 on the solid \Rightarrow gas transition.



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Figure 9.24 The vapour pressure of five metals as a function of temperature plotted on a logarithmic scale. The boiling temperature is defined as the temperature at which the vapour pressure equals atmospheric pressure (0.10135 MPa), which for these substances occurs at: Ag 2433 K; Al 2793 K; Cu 2833 K; Sn 2893 K; Au 3123 K.

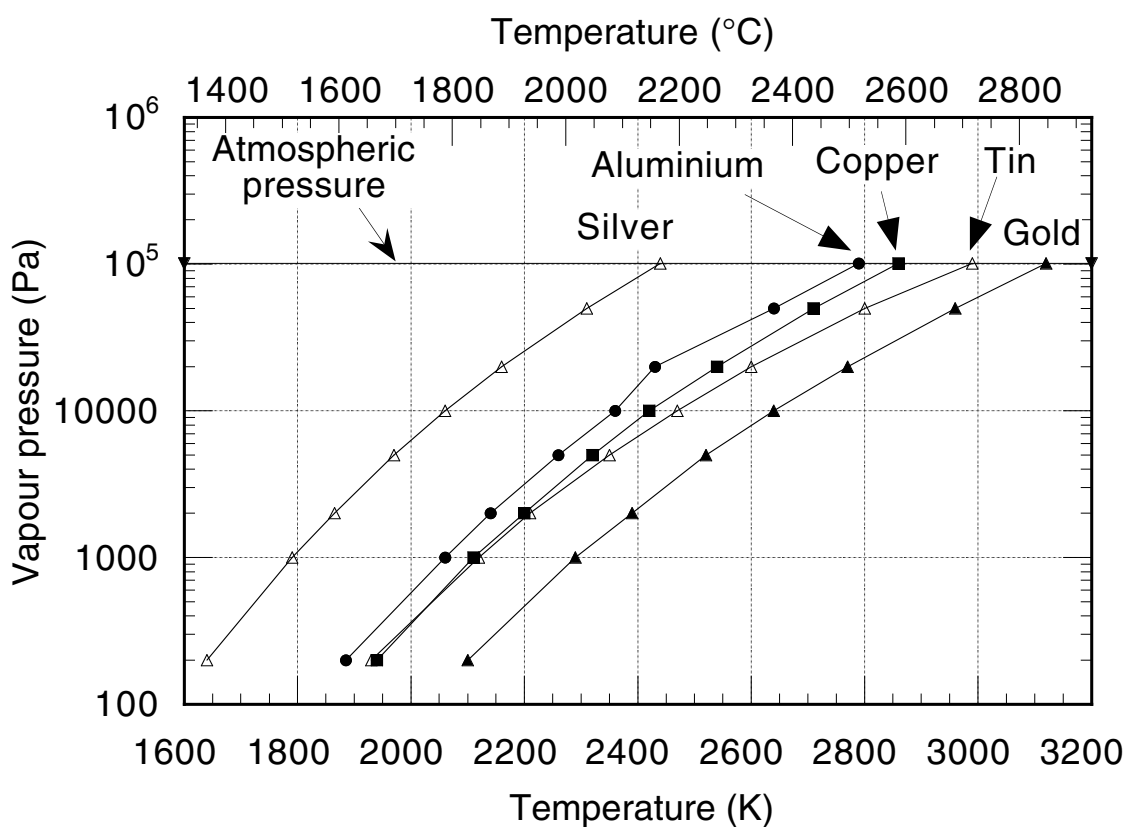
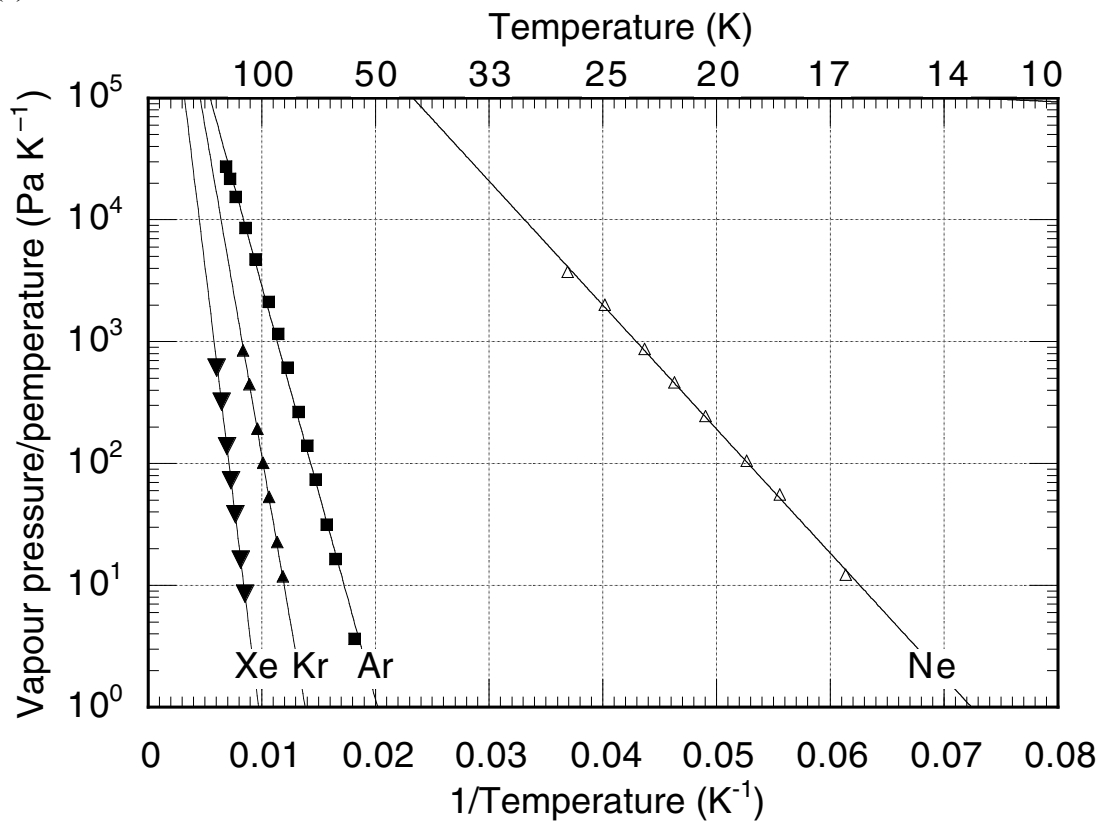


Figure 9.25 The vapour pressure data from (a) Figure 9.23 and (b) Figure 9.24 re-plotted as P/T versus $1/T$ to test the prediction of Equation 11.36. The vertical axis of both graphs is logarithmic and so the linearity of the data indicates good agreement between theory and experiment. The lines on the graph represent least-squares fits to the data. The parameters of the fitted lines are listed in Table 9.11.

(a)



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(b)

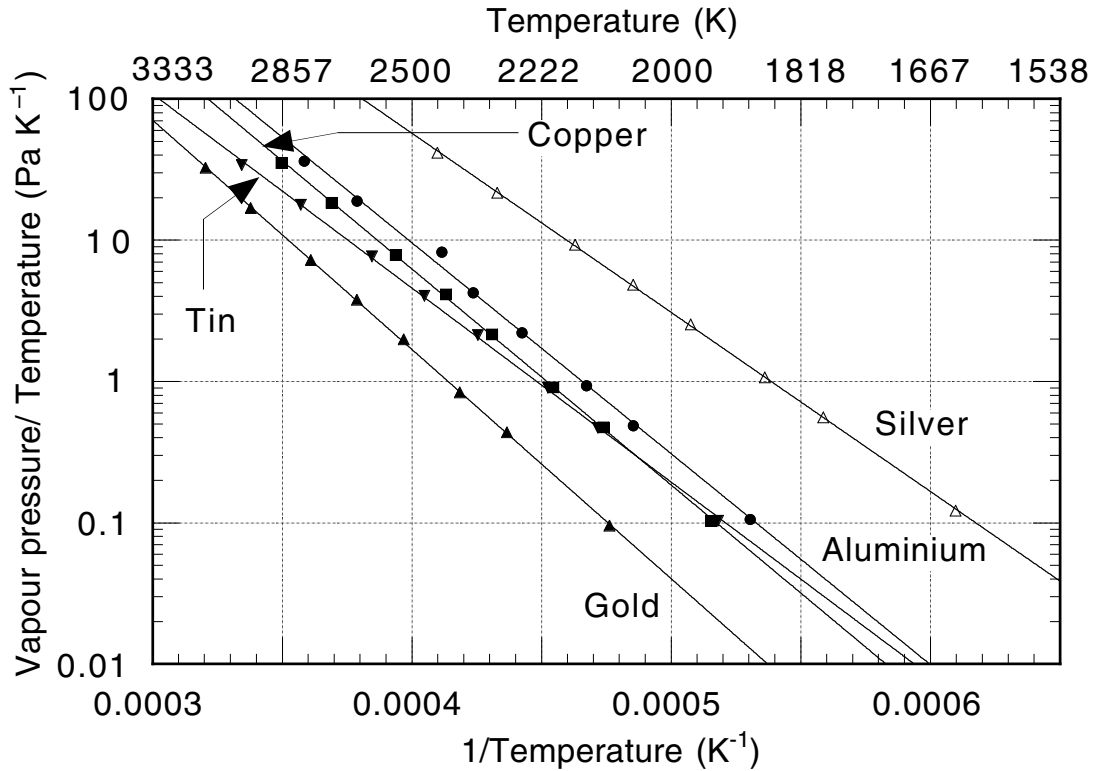


Figure 9.26 Qualitative illustration of the formation of surfaces in (a) liquids made of atoms, such as liquid metals, and (b) liquids consisting of molecules, such as organic molecules. The shapes of the molecules in (b) are entirely illustrative and the gaps between the molecules are left to allow easy identification of the molecules. In (b) the cost of forming a surface may be relatively small if the molecules orient themselves appropriately. However, for organic liquids ‘hopping’ is considerably more difficult owing to the larger size of their molecules and their complex shapes.

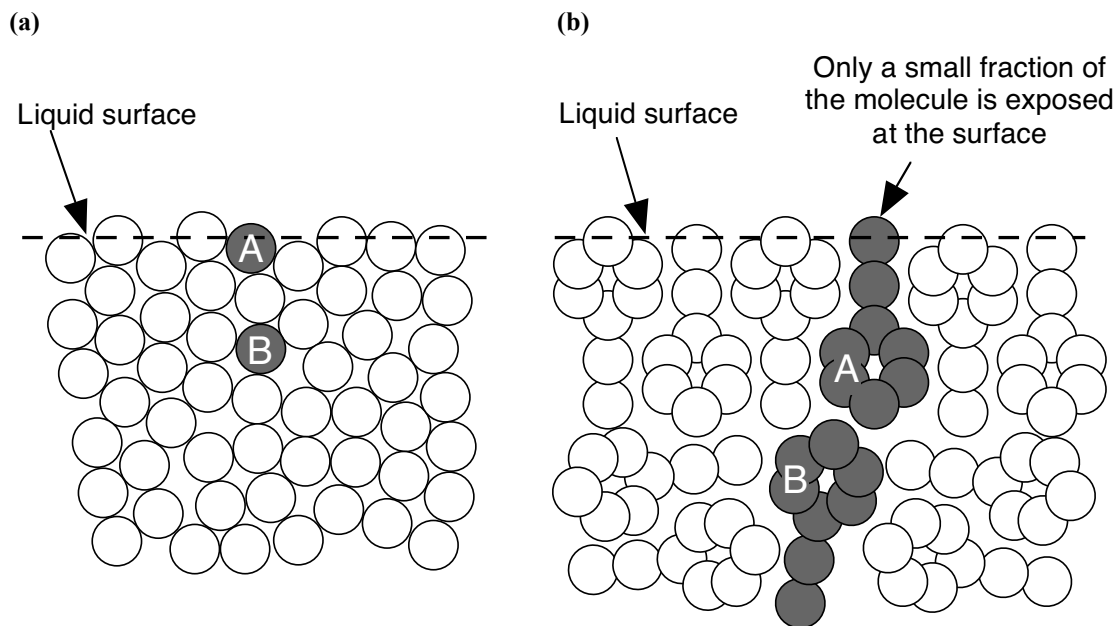


Figure 9.27 The heat capacity of the liquids from Table 9.13 plotted as a function of the relative molecular mass of the molecules of the liquid.

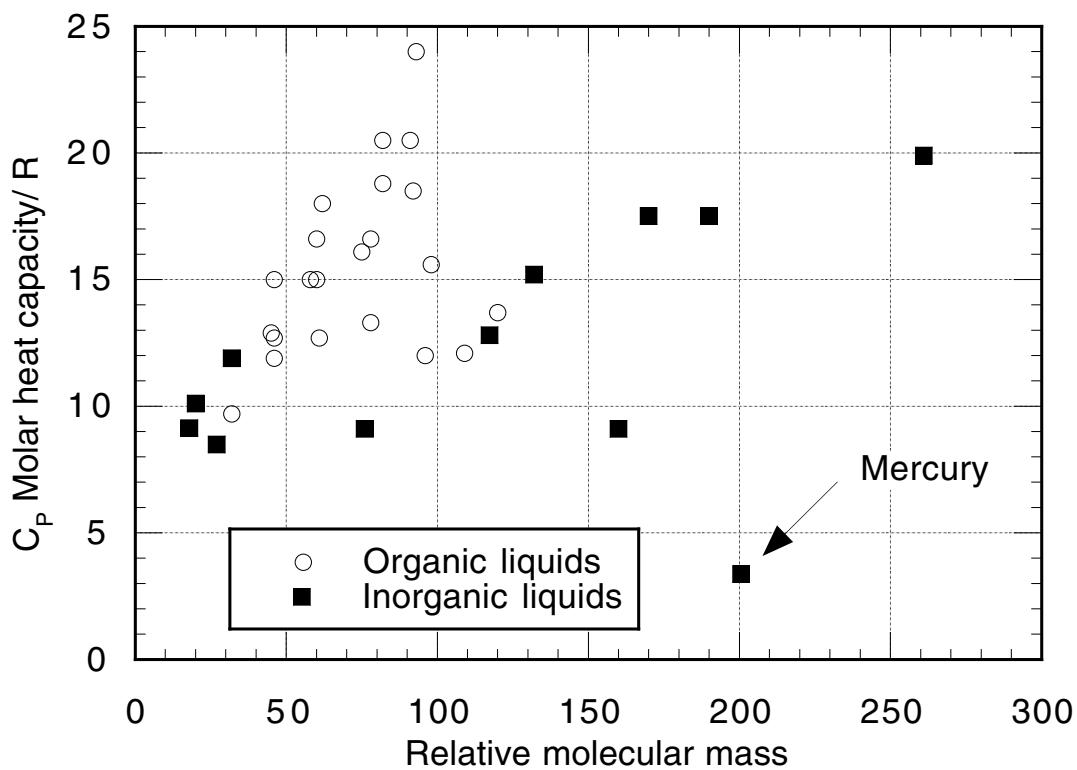


Figure 9.28 The heat capacity of the liquids from Table 9.13 plotted as a function of the number of atoms per molecule. The line has a slope $3R$ per atom as discussed in the text.

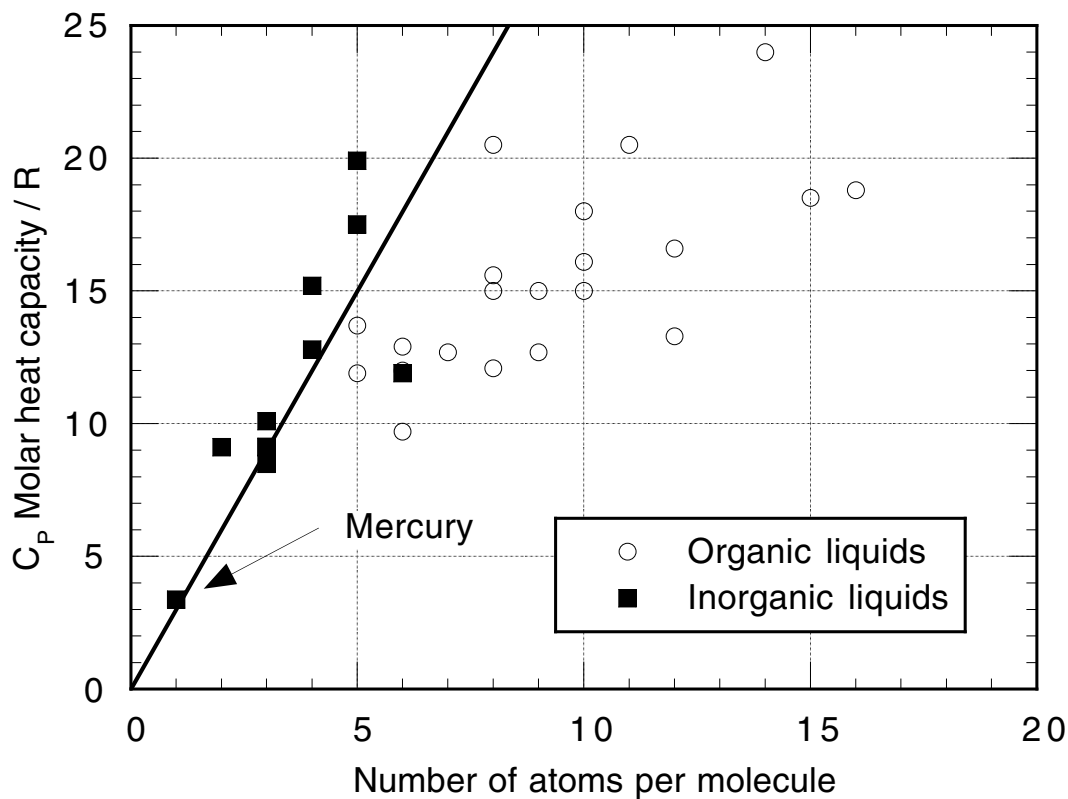
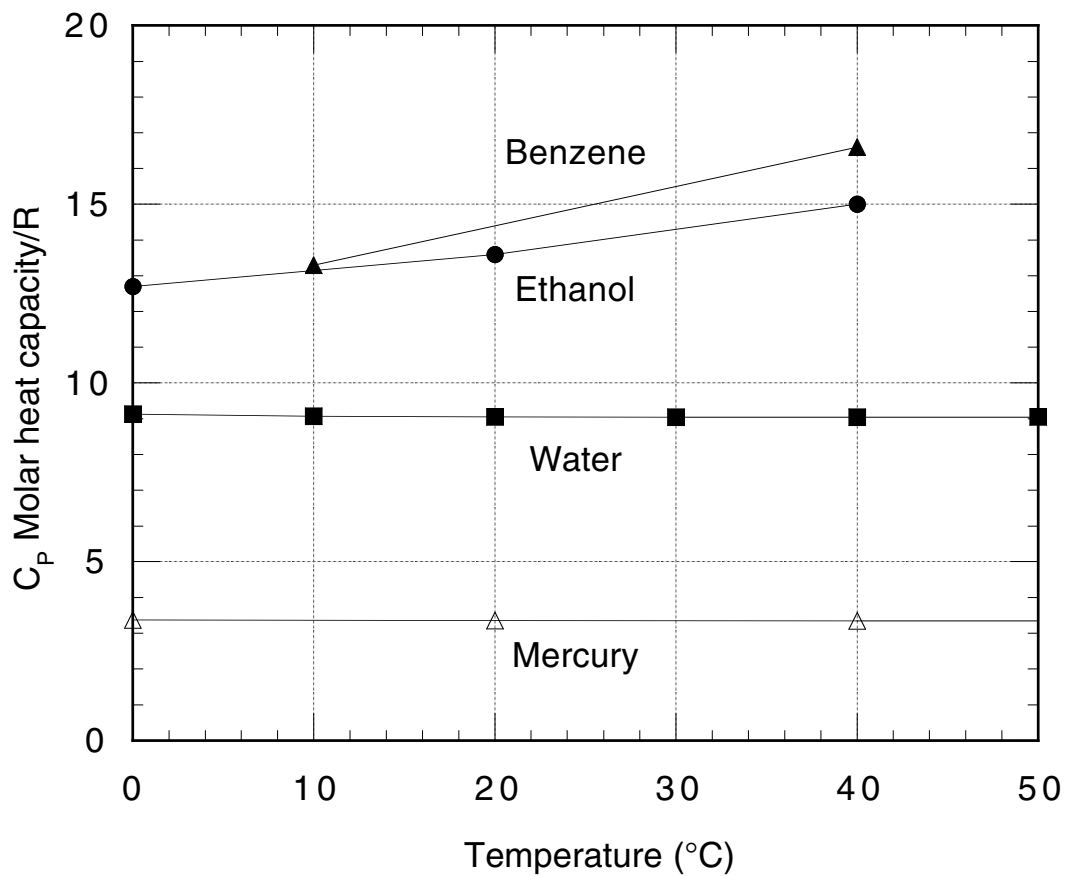


Figure 9.29 The variation with temperature of the heat of various liquids around room temperature. The lines join the data points and are to guide the eye only.



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Figure 9.30 The constant pressure heat capacity of water and mercury showing data in all three phases. The melting and boiling temperatures are water; $T_M = 0^\circ\text{C}$, $T_B = 100^\circ\text{C}$; and mercury $T_M = -38.9^\circ\text{C}$, $T_B = 356.6^\circ\text{C}$.

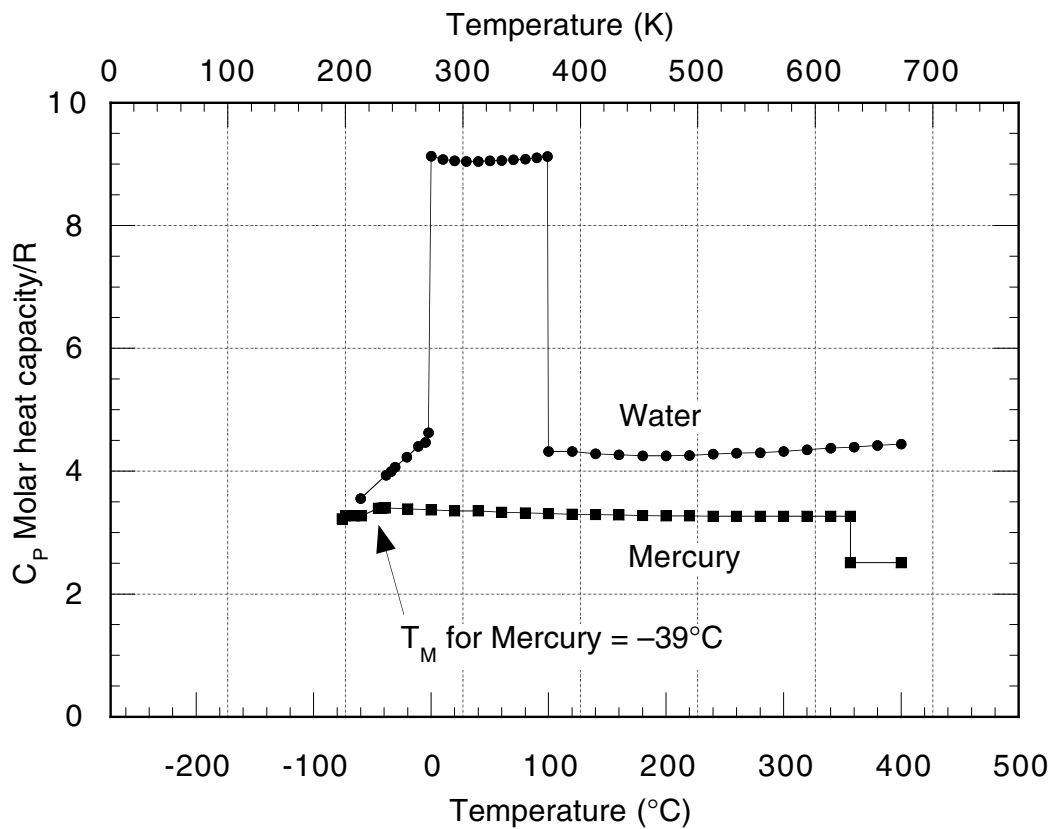
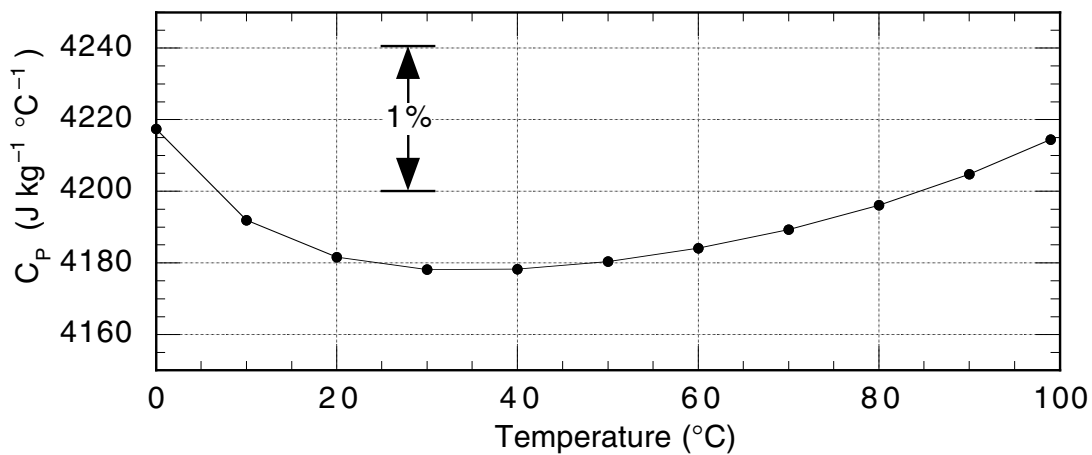


Figure 9.31 Detail from Figure 9.29 showing the variation of the heat capacity of water in its liquid state.



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Figure 9.32 (a) Data from Table 9.12 showing the thermal conductivity of miscellaneous non-metallic liquids in units of $\text{W m}^{-1} \text{K}^{-1}$. (b) Thermal conductivity of insulating liquids shown over a larger range. (c) The data from (b) re-plotted on a logarithmic scale.

(a)

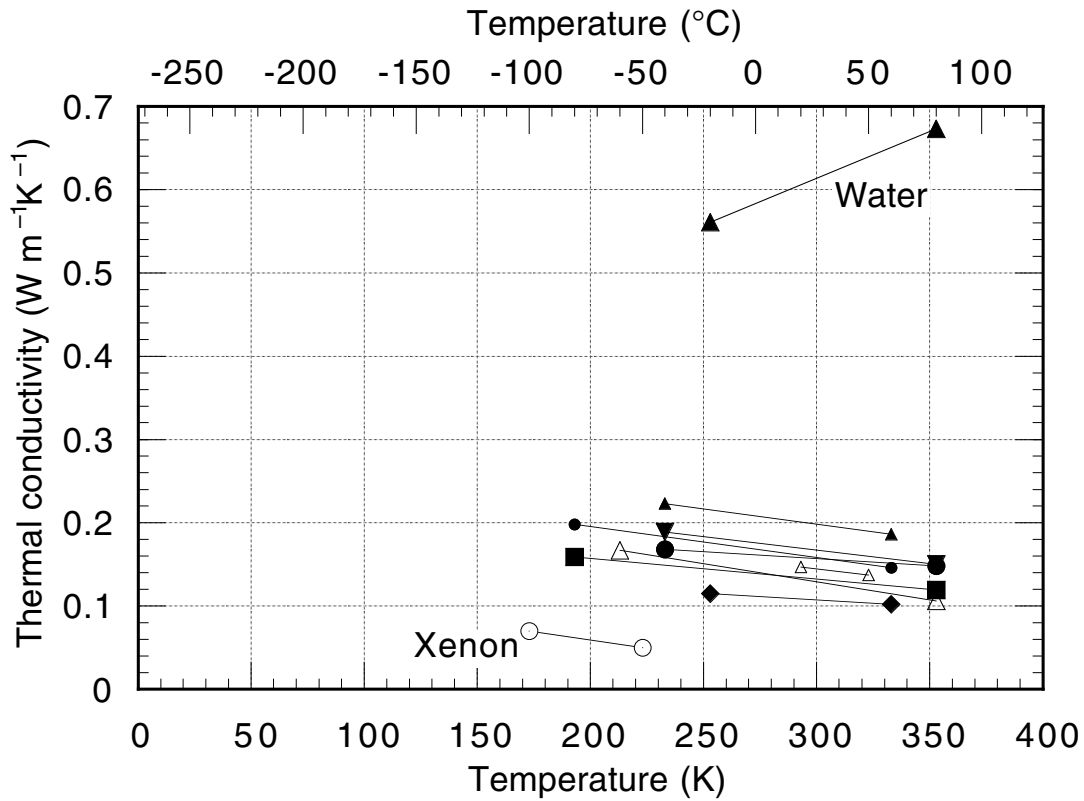


Figure 9.32 (a) Data from Table 9.12 showing the thermal conductivity of miscellaneous non-metallic liquids in units of $\text{W m}^{-1} \text{K}^{-1}$. (b) Thermal conductivity of insulating liquids shown over a larger range. (c) The data from (b) re-plotted on a logarithmic scale.

(b)

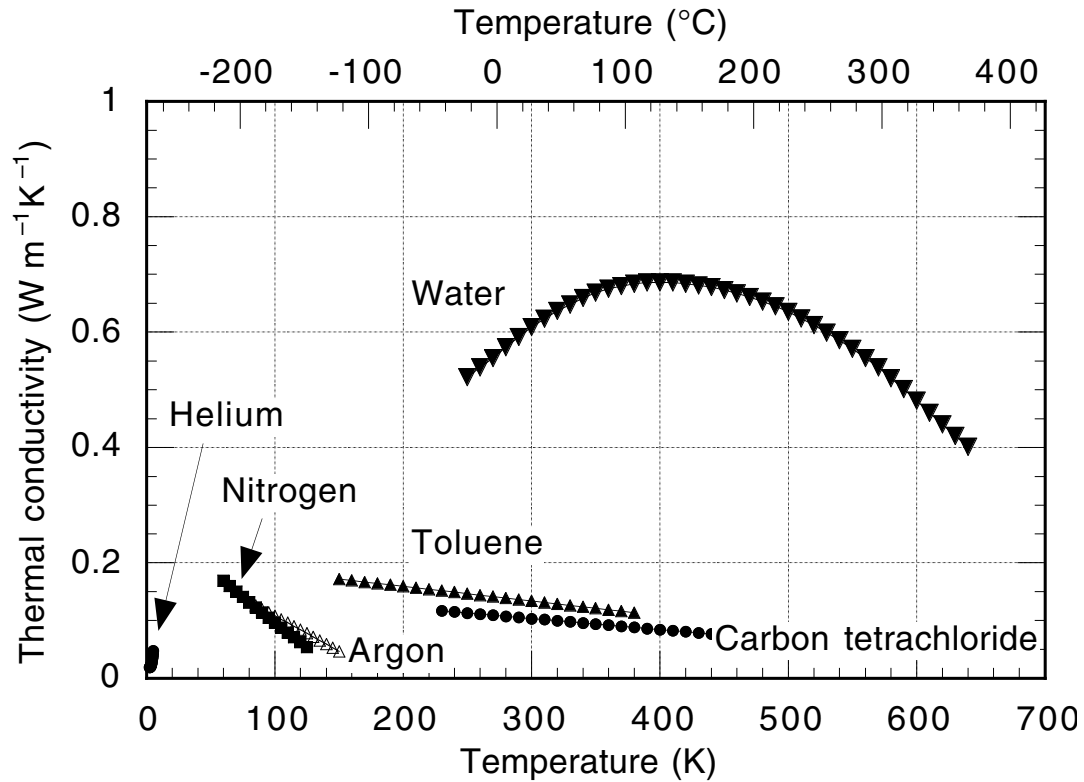


Figure 9.32 (a) Data from Table 9.12 showing the thermal conductivity of miscellaneous non-metallic liquids in units of $\text{W m}^{-1} \text{K}^{-1}$. (b) Thermal conductivity of insulating liquids shown over a larger range. (c) The data from (b) re-plotted on a logarithmic scale.

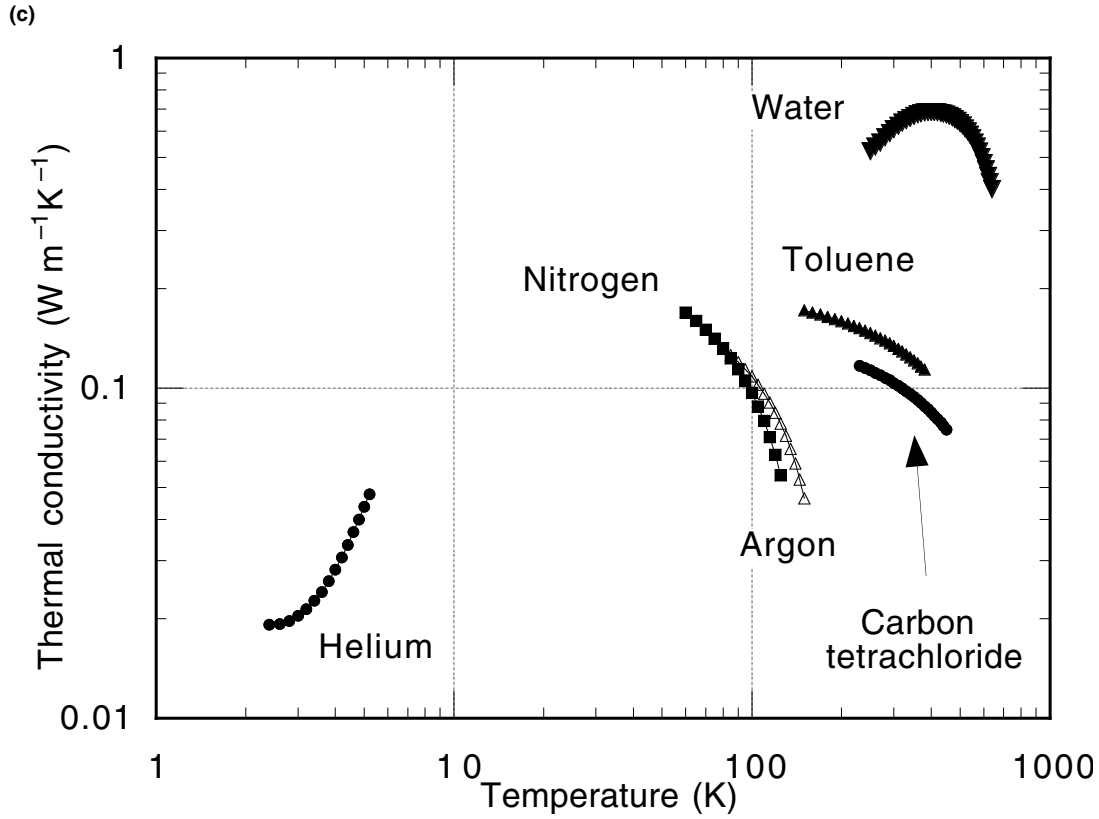


Figure 9.33 Data from Table 9.13 showing the thermal conductivity of elemental metals in their liquid state in units of $\text{W K}^{-1} \text{m}^{-1}$.

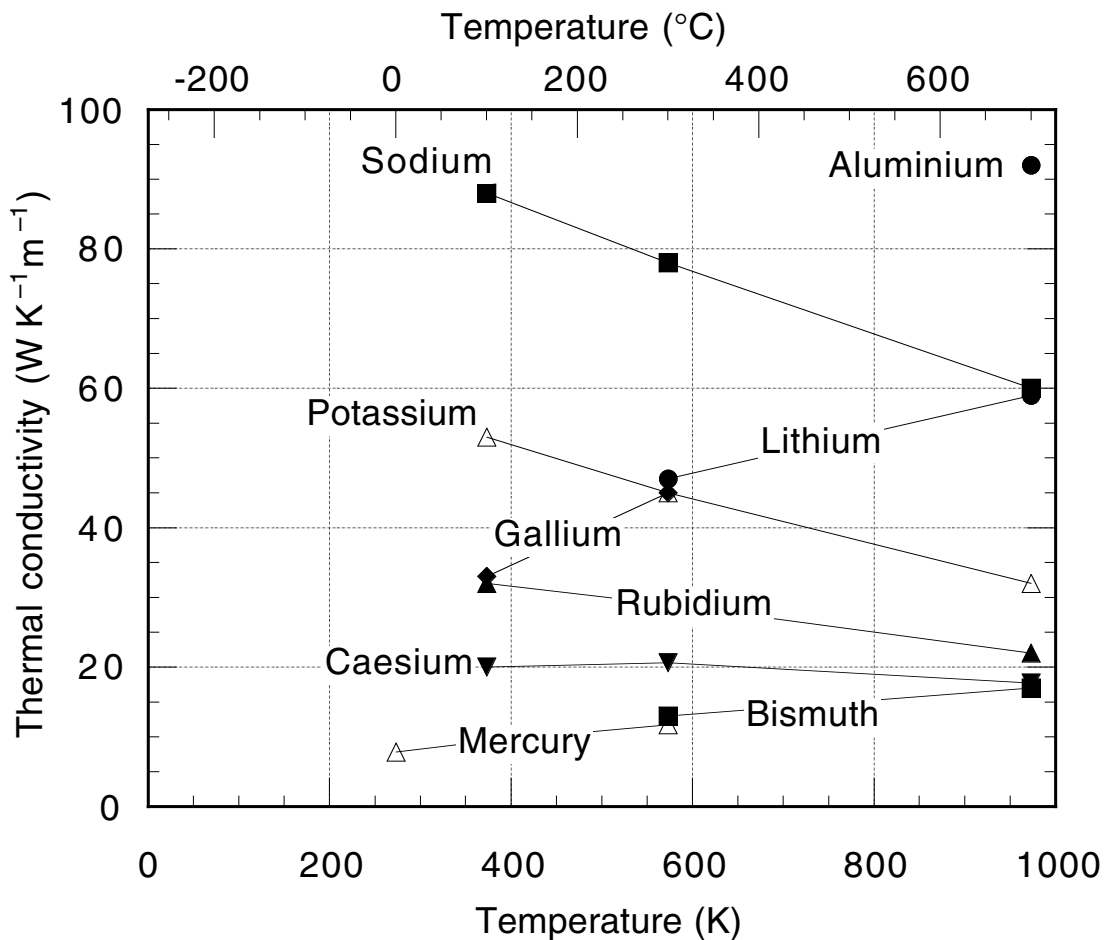


Figure 9.34. From the point of view of thermal conductivity, a liquid may be considered as being a solid-like matrix with pockets of gas-like ‘free space’. From the data on the density of liquids, we estimate that roughly 10% of a liquid is ‘free space’. We can estimate the thermal conductivity of the liquid if we imagine separating out the free-space part of the liquid and considering heat to pass through a gas-like layer, and then a solid-like amount of substance. The arrow in each figure indicates the direction of heat transport.

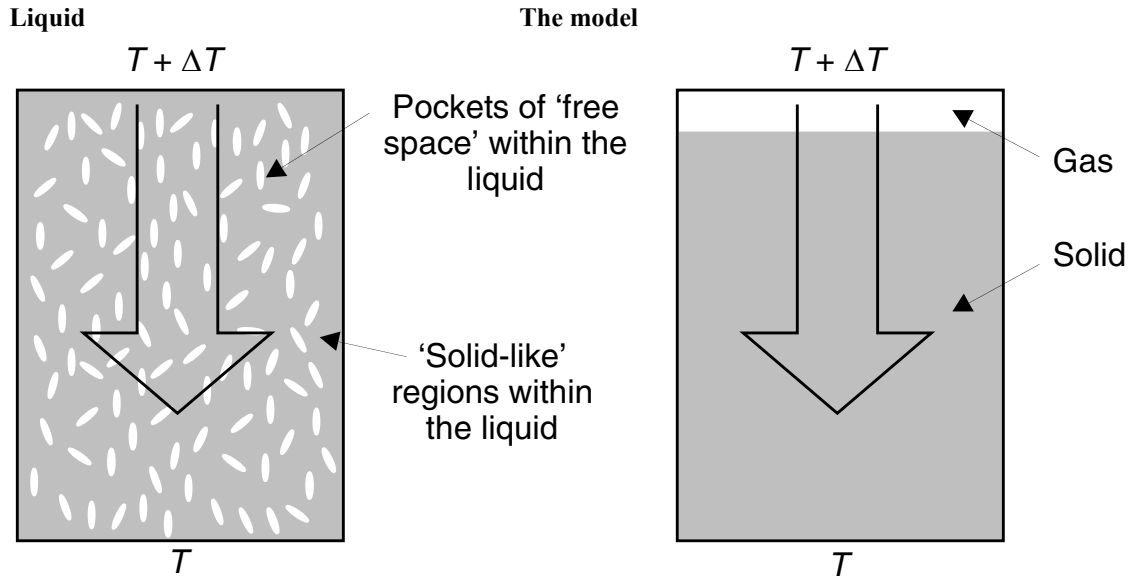


Figure 9.35 The resistivity of elemental metals with low melting points. Notice that the data show a significant increase in resistivity from below the melting temperature to above it. Note: The lines which connect the data points are drawn only to guide the eye. In actuality data were available at closely spaced temperatures, it would show that at the transition from liquid to solid there would be a sharp increase in resistivity.

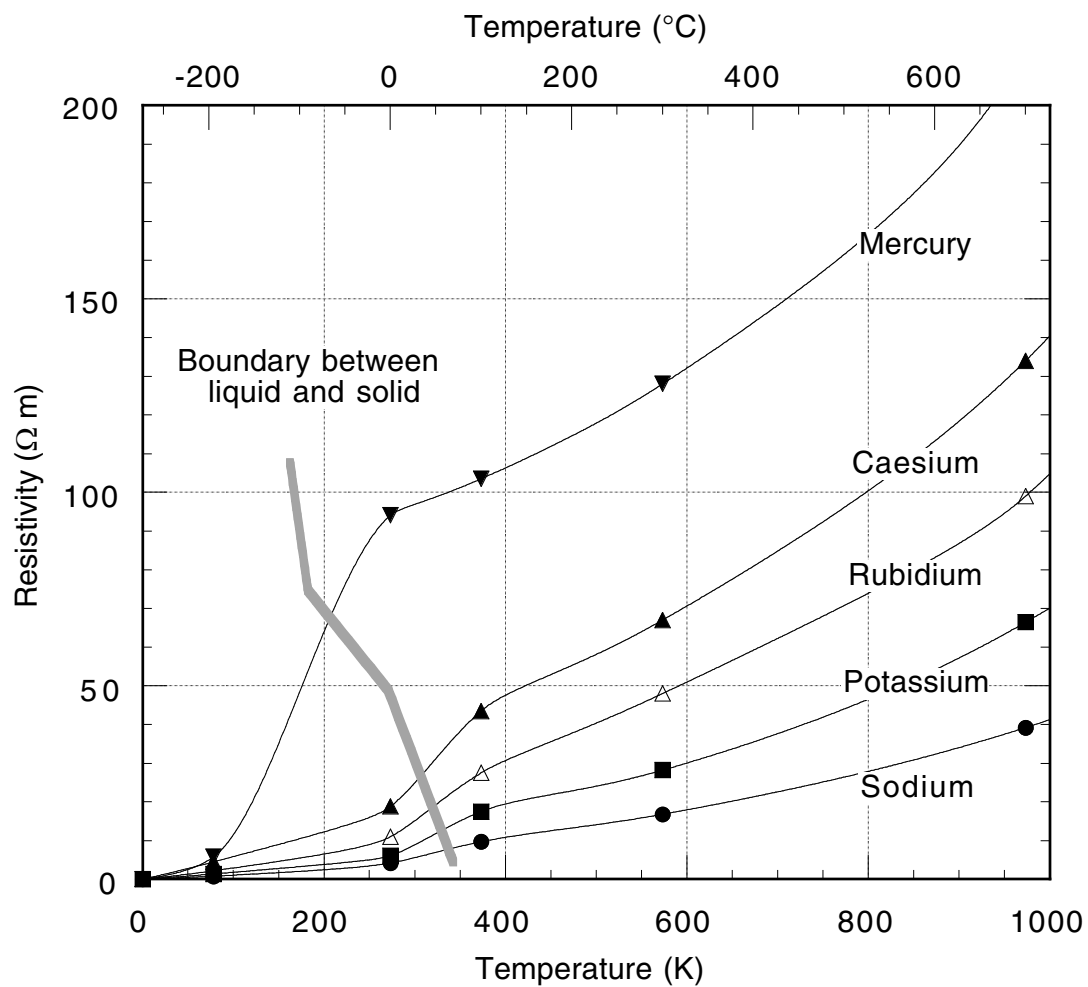


Figure 9.36 A schematic illustration of the way an electron wave can be scattered several times through small angles and eventually result in randomisation of the electrons initial momentum.

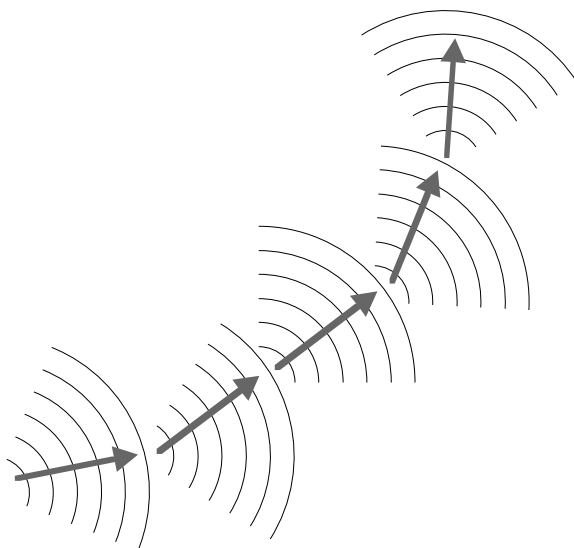


Figure 9.37 The difference of the relative dielectric permittivity from unity, $\epsilon - 1$, plotted as function of the molecular mass of the molecules of various electrically insulating liquids. Lines have been drawn to attract attention to the trend in the alcohols, to which water appears to be roughly related. All the elements in Table 9.16 appear as points close to the x -axis in this figure.

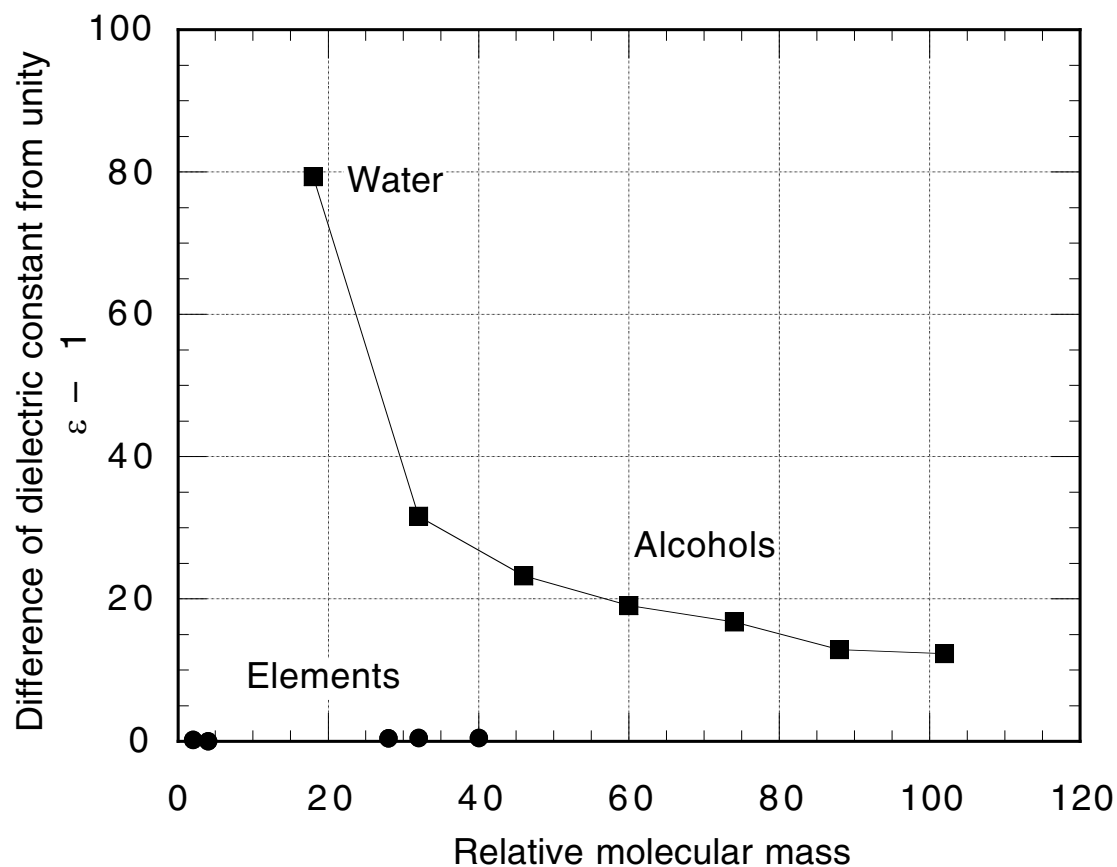


Figure 9.38 The refractive index of a water as a function of wavelength. The shaded region corresponds to the visible region of the spectrum.

