

CHAPTER 5

Figures

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Figure 5.1: Heating a gas at constant pressure. Notice the increase in volume and reduction in density.

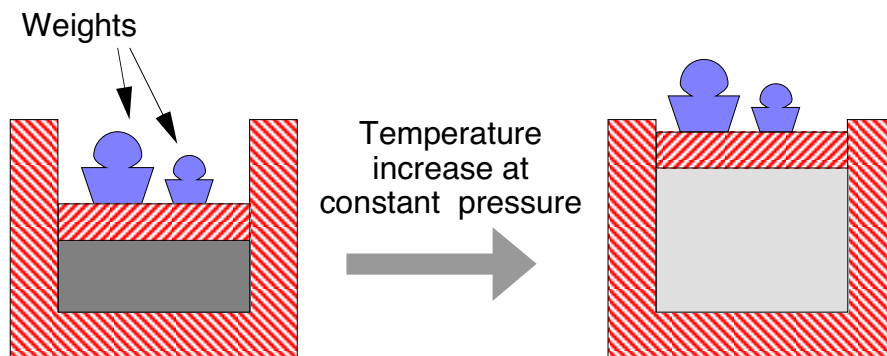


Figure 5.2: Heating a gas at constant volume. Notice the pressure (indicated by the weights) has increased.

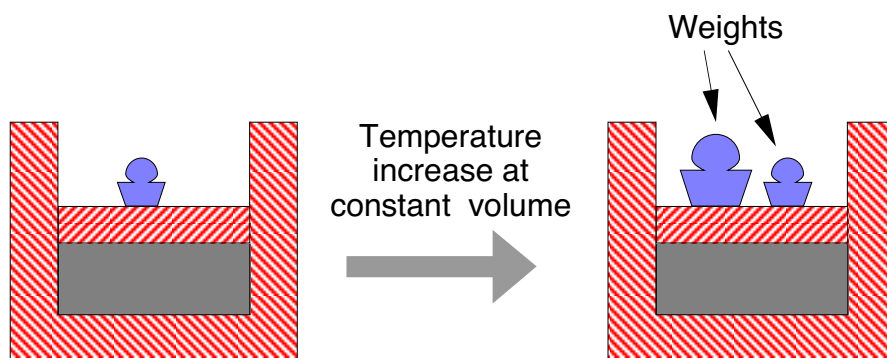


Figure 5.3: The heat capacity of monatomic gases C_p versus absolute temperature (Table 5.6). Data for temperatures less than the boiling point are not plotted. Notice that at the resolution of the measurement, the gases have the same heat capacity across a temperature variation of over an order of magnitude.

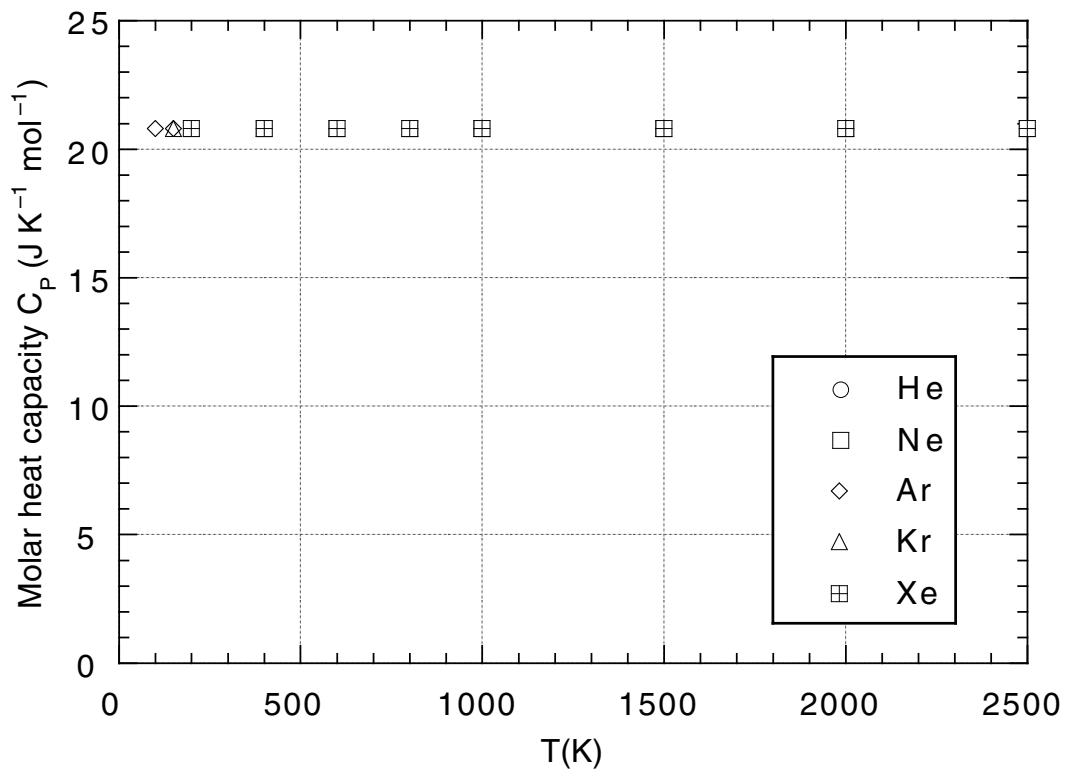


Figure 5.4: The heat capacity of diatomic gases versus absolute temperature (Table 5.7). Data for temperatures below the boiling point are not plotted. Notice that the heat capacities increase with temperature. The lines through the data points are drawn to guide the eye

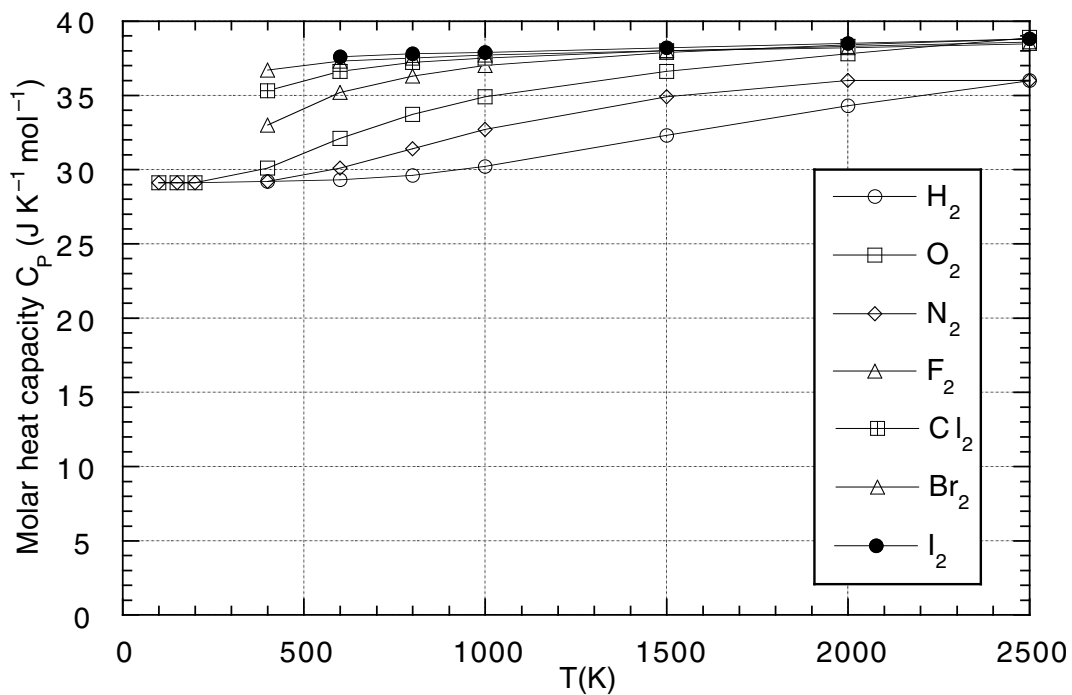


Figure 5.5 Histogram of values of γ in Table 5.8. The column height indicates how common it is to find γ within ± 0.01 of the value specified on the x -axis. Notice how the data are clustered in groups that are identifiable as monatomic, diatomic, polyatomic or high pressure.

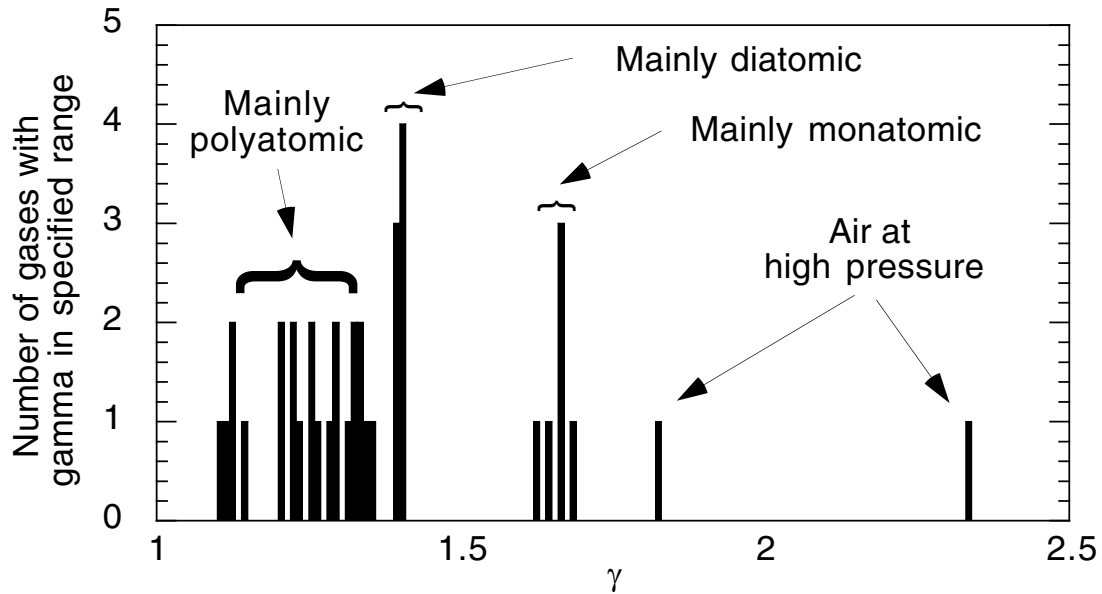


Figure 5.6 The input of heat into a gas under conditions of constant pressure. The figure shows gas trapped in a thermally insulated piston device with cross-sectional area A . The piston is free to move so that it will finally stop when the net force on the piston is zero.

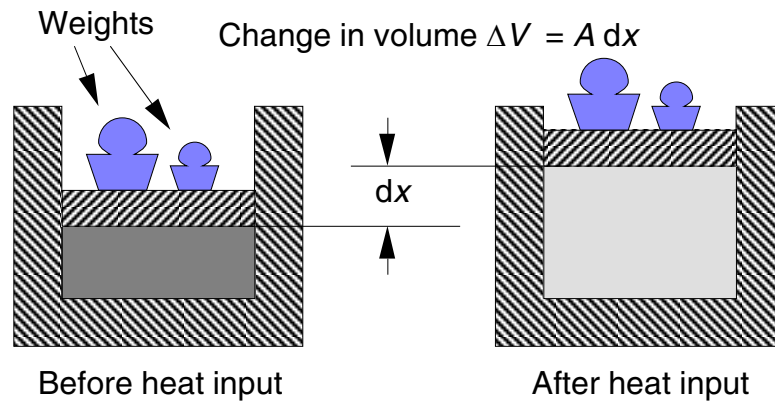
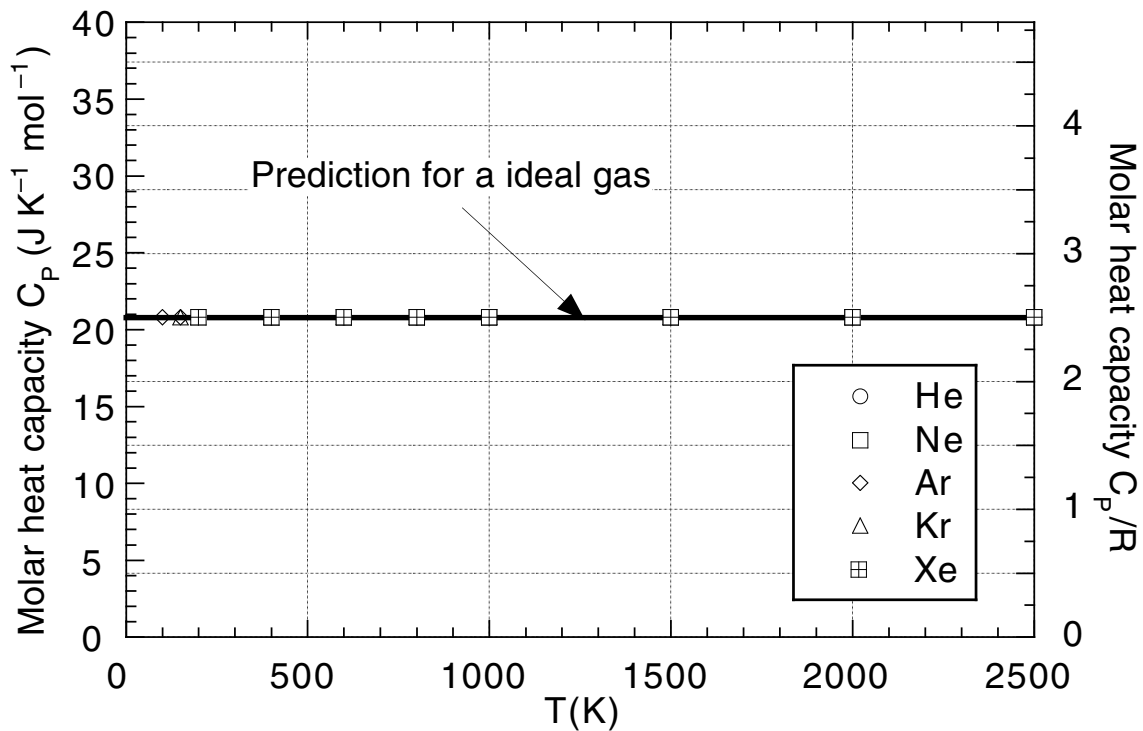


Figure 5.7 Comparison of the prediction of theory with experimental results for monatomic gases. The right-hand axis shows C_p in units of the gas constant R .



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Figure 5.8 The experimental results for diatomic gases compared with the prediction for monatomic gases. The right-hand axis shows C_p in units of the gas constant R . The data exceed the prediction for monatomic gases by at least R at low temperatures, increasing to around 2 to 2.5 R at high temperatures.

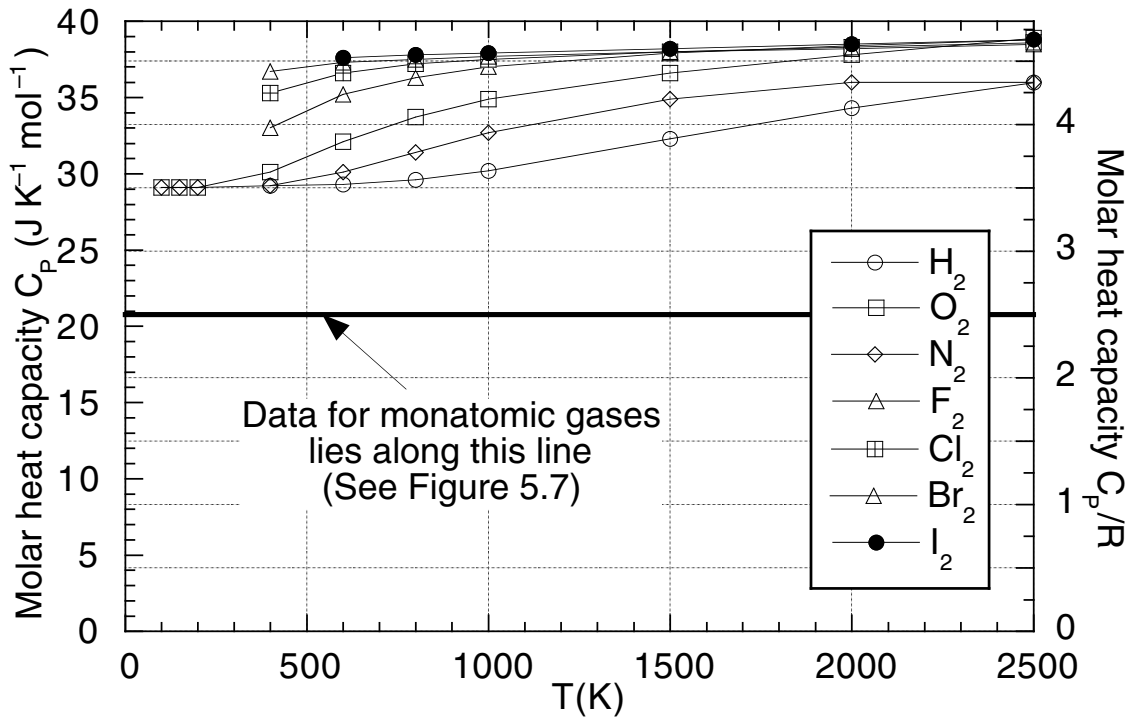


Figure 5.9 Three degrees of freedom of a gas molecule are associated with kinetic energy of motion in each of the x -, y -, and z - directions.

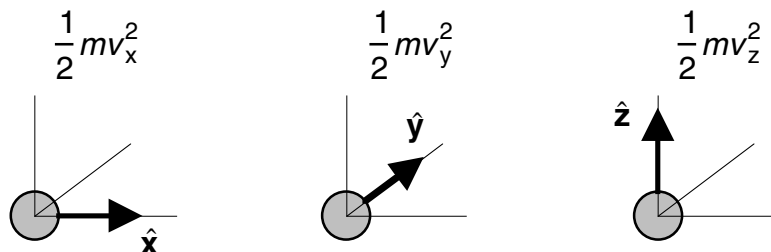


Figure 5.10 The three degrees of freedom of a diatomic molecule associated with rotation about the x -, y - and z -axes.

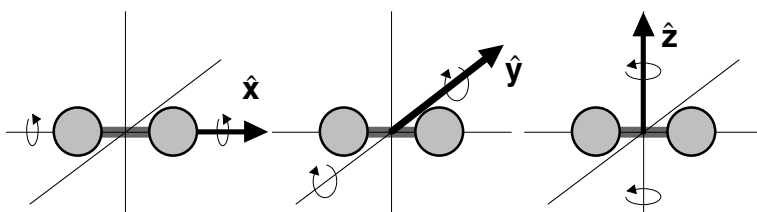


Figure 5.11 The degree of freedom of a diatomic molecule associated with internal vibration.

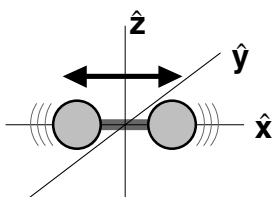


Figure 5.12 The experimental C_p results for helium and oxygen plotted as a function of temperature, extracted from Figures 5.3 and 5.4 respectively. The left-hand axis gives C_p in units of $\text{J K}^{-1} \text{mol}^{-1}$ while the right-hand axis shows the number of accessible degrees of freedom inferred using Equation 5.48.

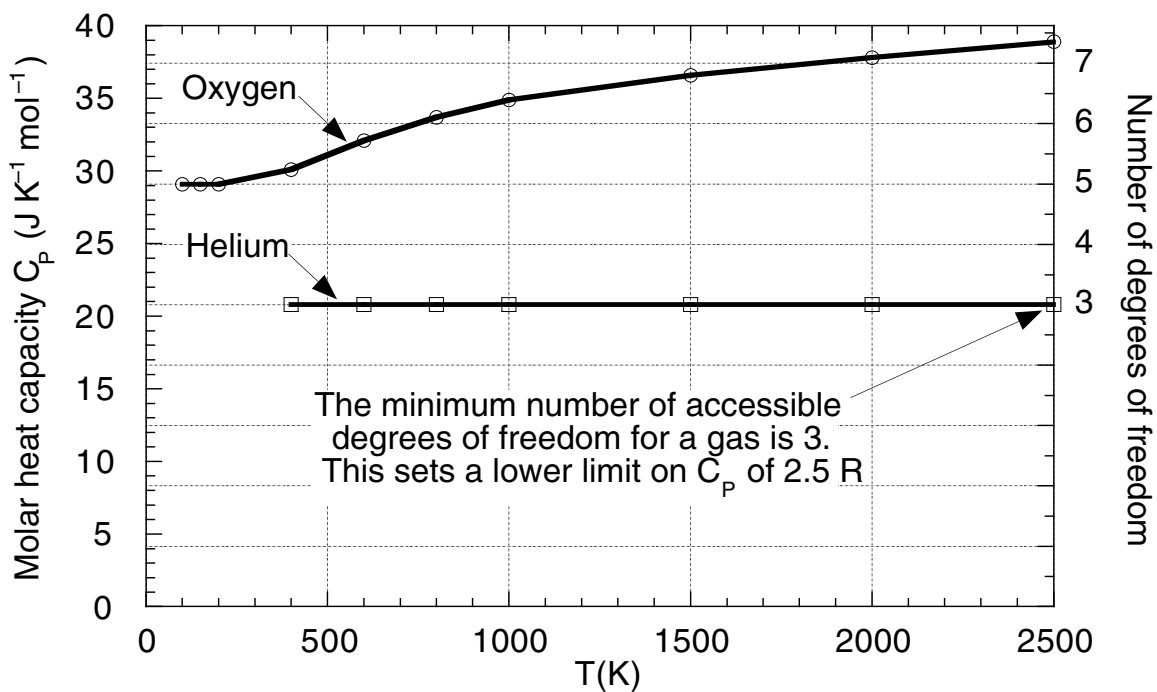


Figure 5.13 (a) The variation of pressure with volume during an isothermal and adiabatic expansion. (b) An apparatus for realising an isothermal expansion requires some means of adding heat to the gas. (c) In an adiabatic expansion no heat flows into or out of the gas. Notice in (b) and (c) that the pressure in both cases is the same at the end of the expansion, but the volume is larger in the isothermal case, as indicated in (a).

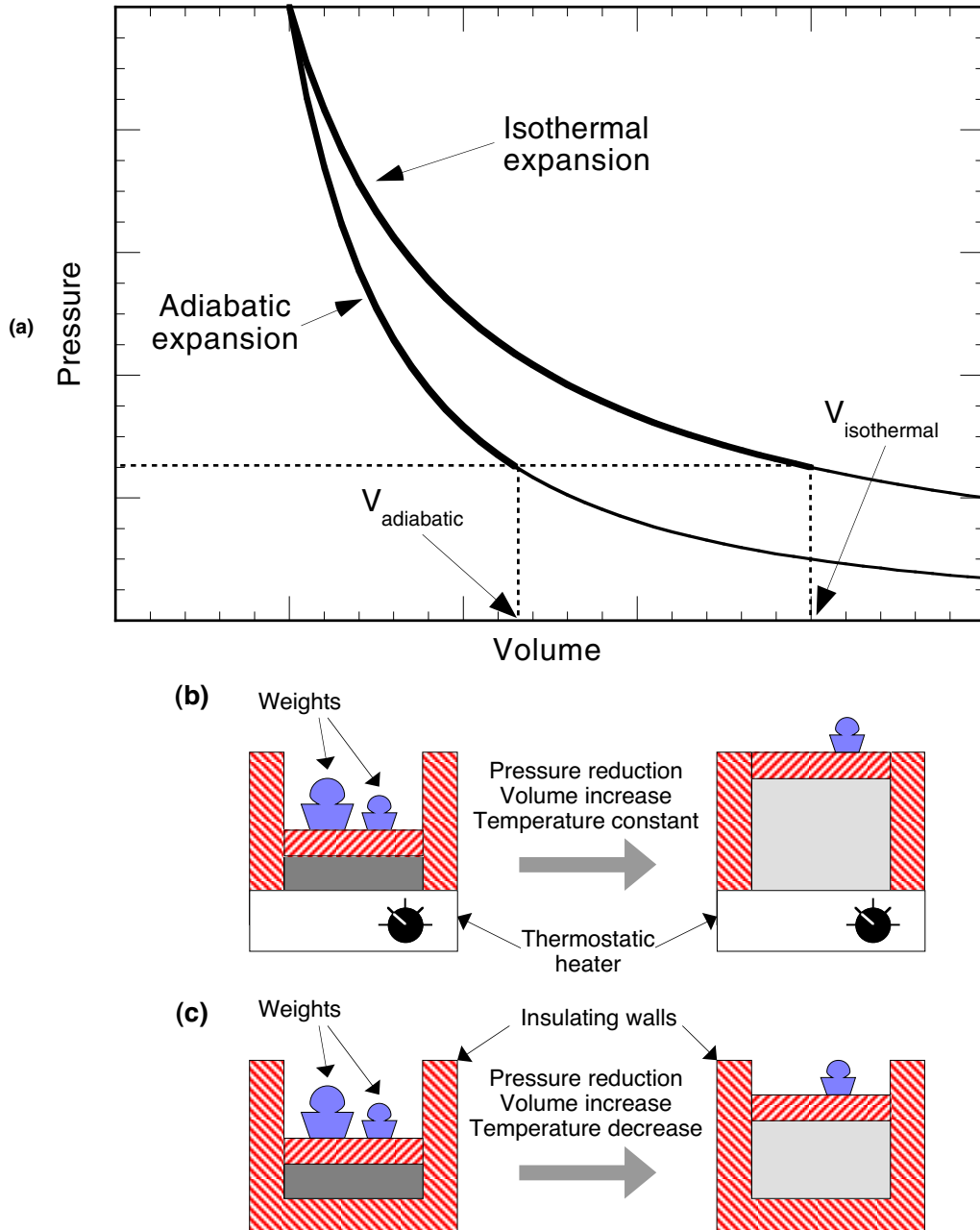


Figure 5.14 *PV* diagram showing the gradient of the pressure volume curve and the relationship to the bulk modulus and compressibility.

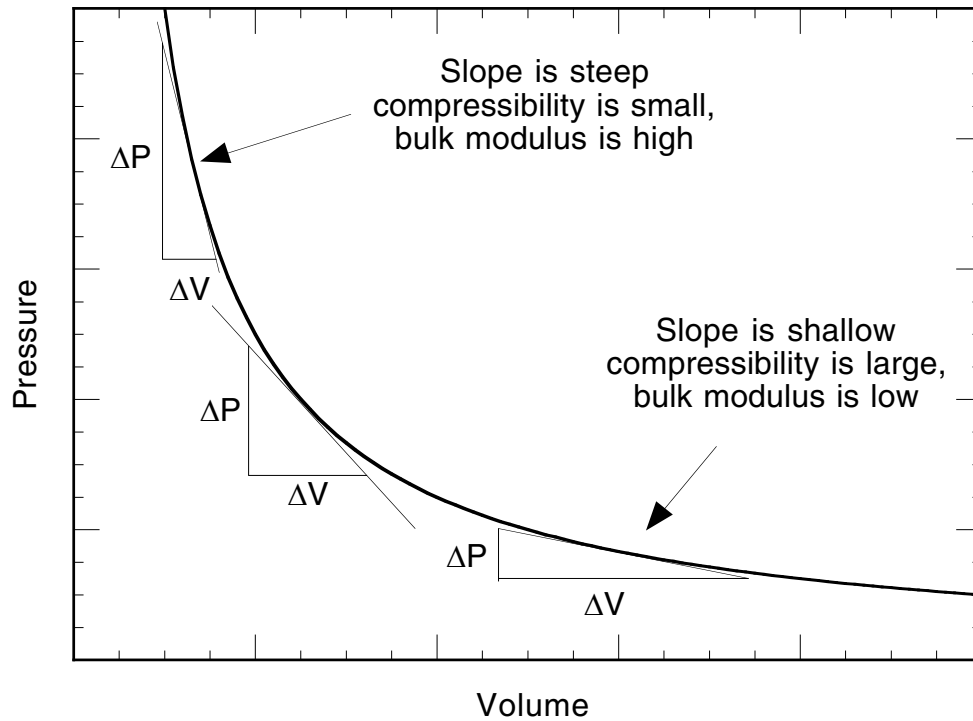


Figure 5.15 Two-step analysis of an adiabatic expansion. An adiabatic expansion can be considered as the sum of two steps which are simpler to analyse: an isothermal expansion, and then an isochoric (constant volume) cooling. This analysis allows us to determine the relationship between the initial pressure and volume and the final pressure and volume.

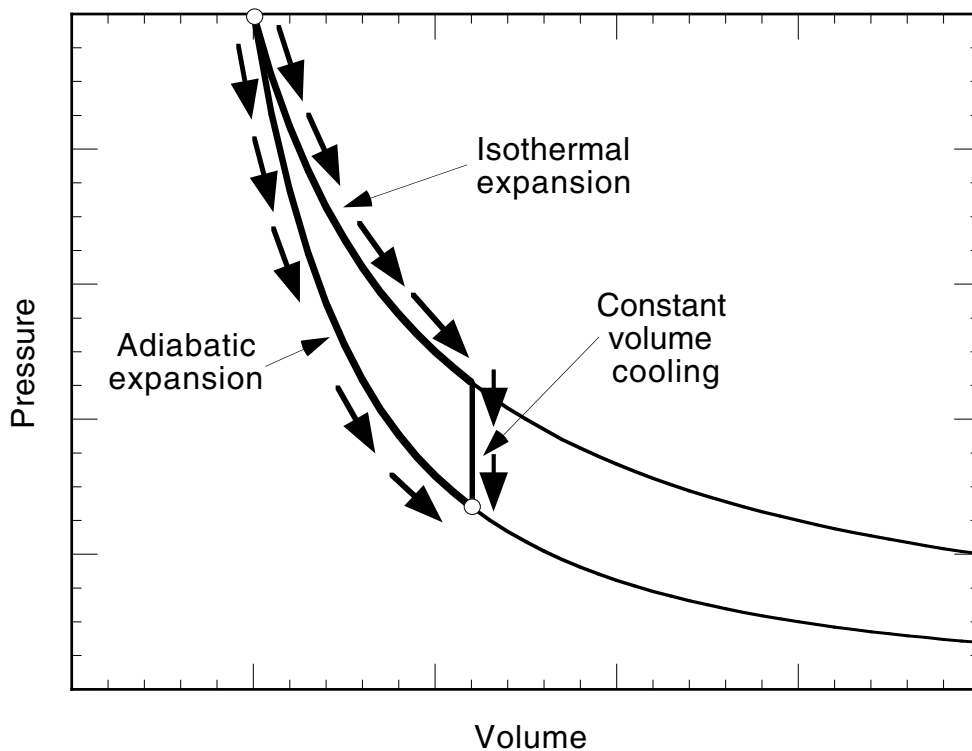


Figure 5.16 Convection occurs when heating produces a region of low-density gas (hot) which is beneath a region of high-density gas (cold). This arrangement is unstable and the low-density (hot) gas rises and moves to the colder part of the chamber. When it reaches the colder part of the chamber, it cools. It then gives up thermal energy $zC_p\Delta T$. When convection occurs, the heat flow does not depend on the intrinsic thermal conductivity of gas, but on its heat capacity and the rate of flow of gas.

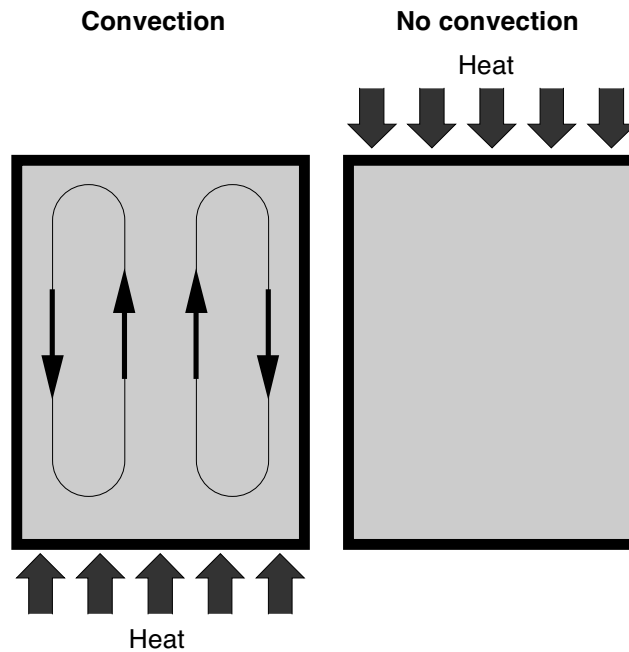
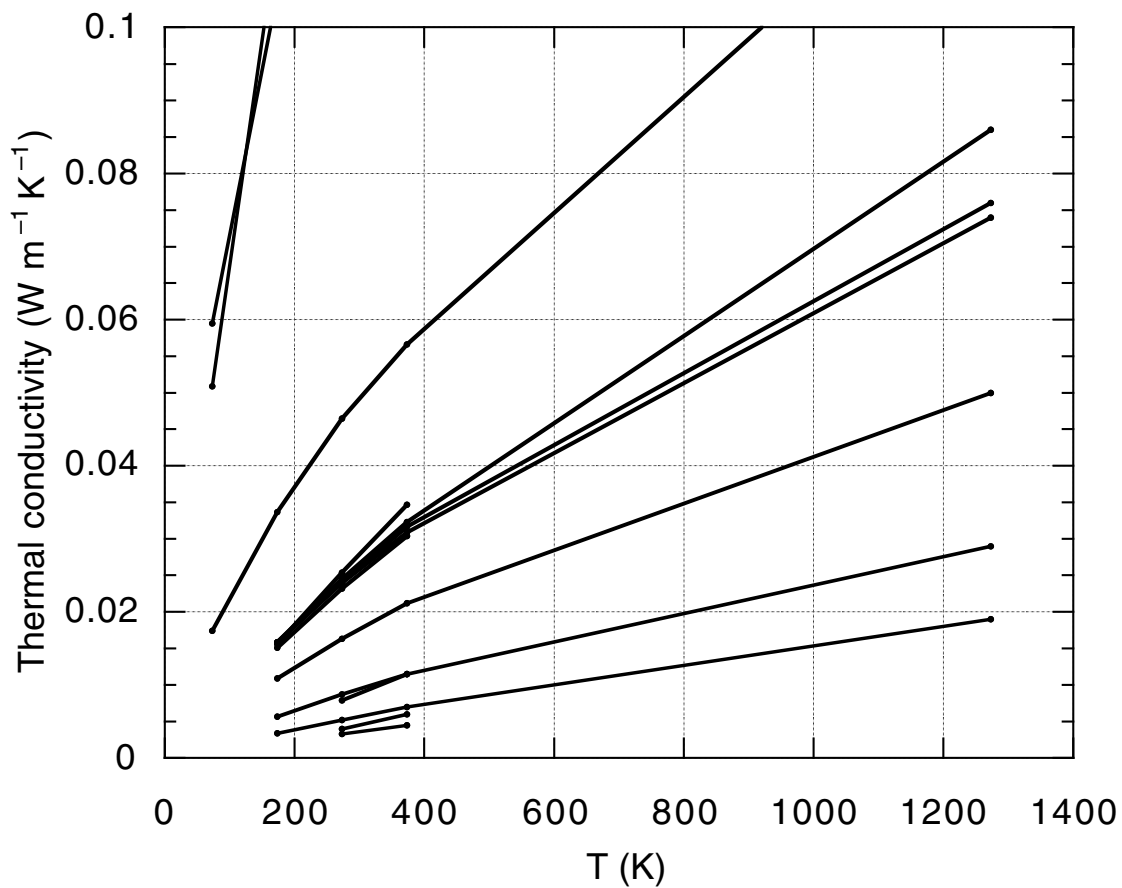


Figure 5.17 Variation of the thermal conductivity of the gases from Table 5.11 with absolute temperature. All the curves, monatomic, diatomic and polyatomic behave broadly similarly, but the absolute magnitude of conductivity varies significantly from one gas to another. The lines joining the data points are a guide to the eye only.



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Figure 5.18 Variation of the thermal conductivity of argon with pressure. The lines join the data points and are a guide to the eye only. Notice that the pressure scale is logarithmic and represents a pressure range of 5 orders of magnitude.

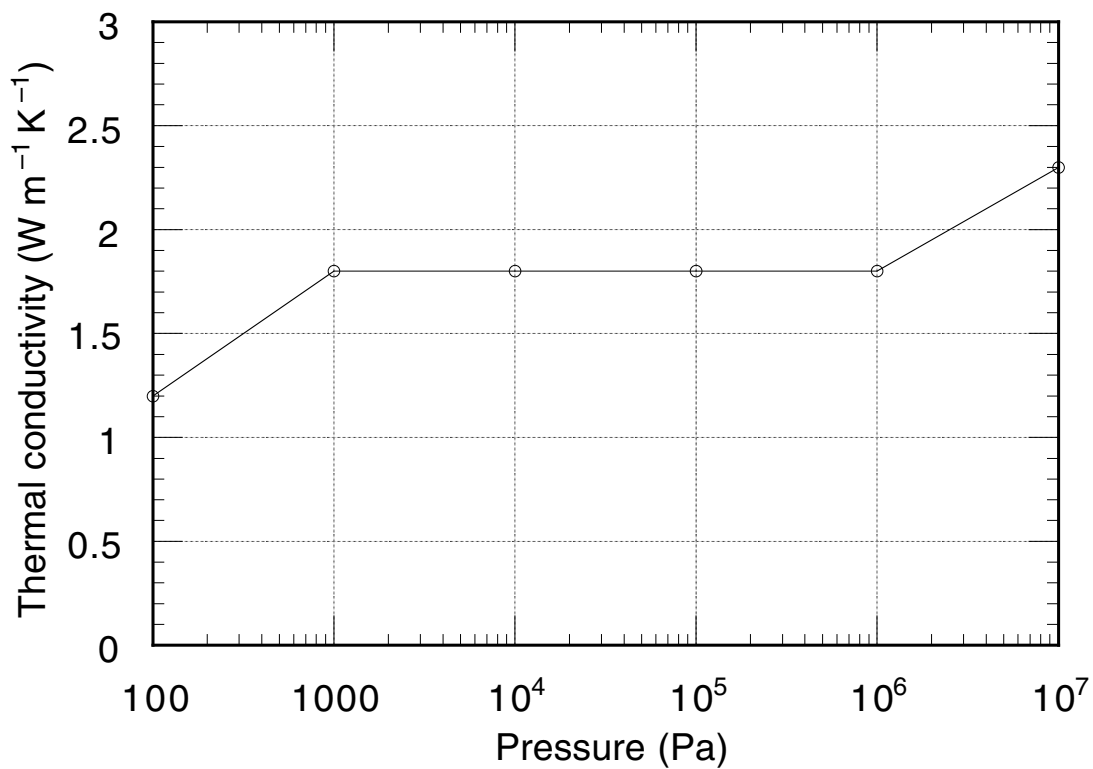
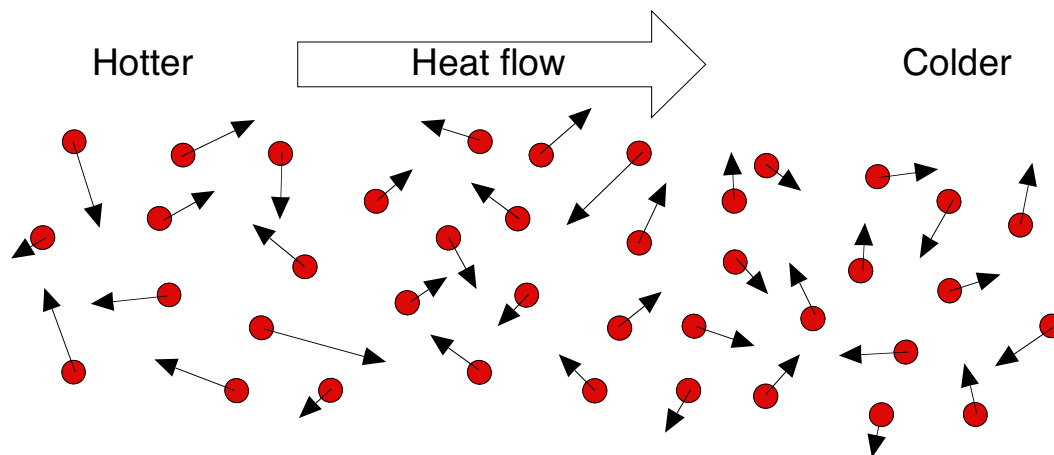
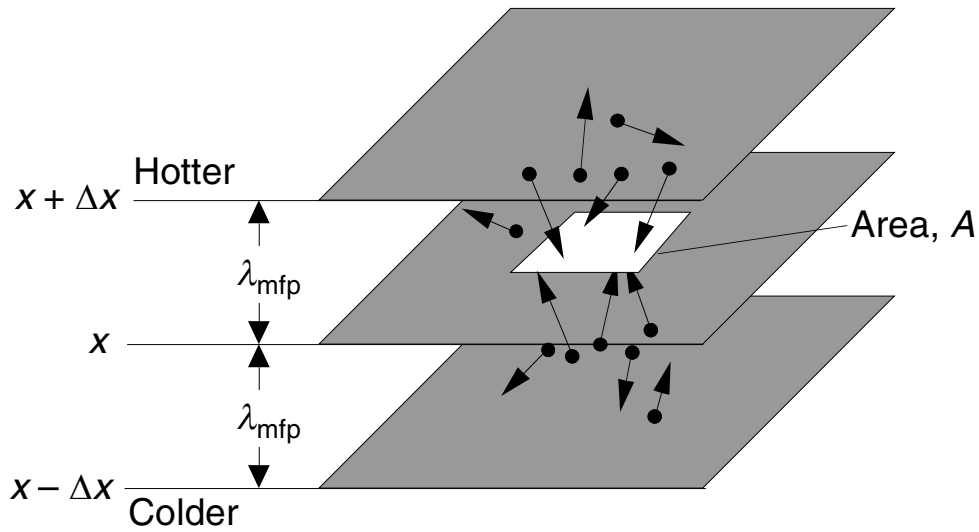


Figure 5.19 Illustration of the basic process by which we imagine heat flow to take place. Notice that the *average* speed of molecules (represented by the length of the arrows) in the hotter region is greater than the *average* speed in the colder region.



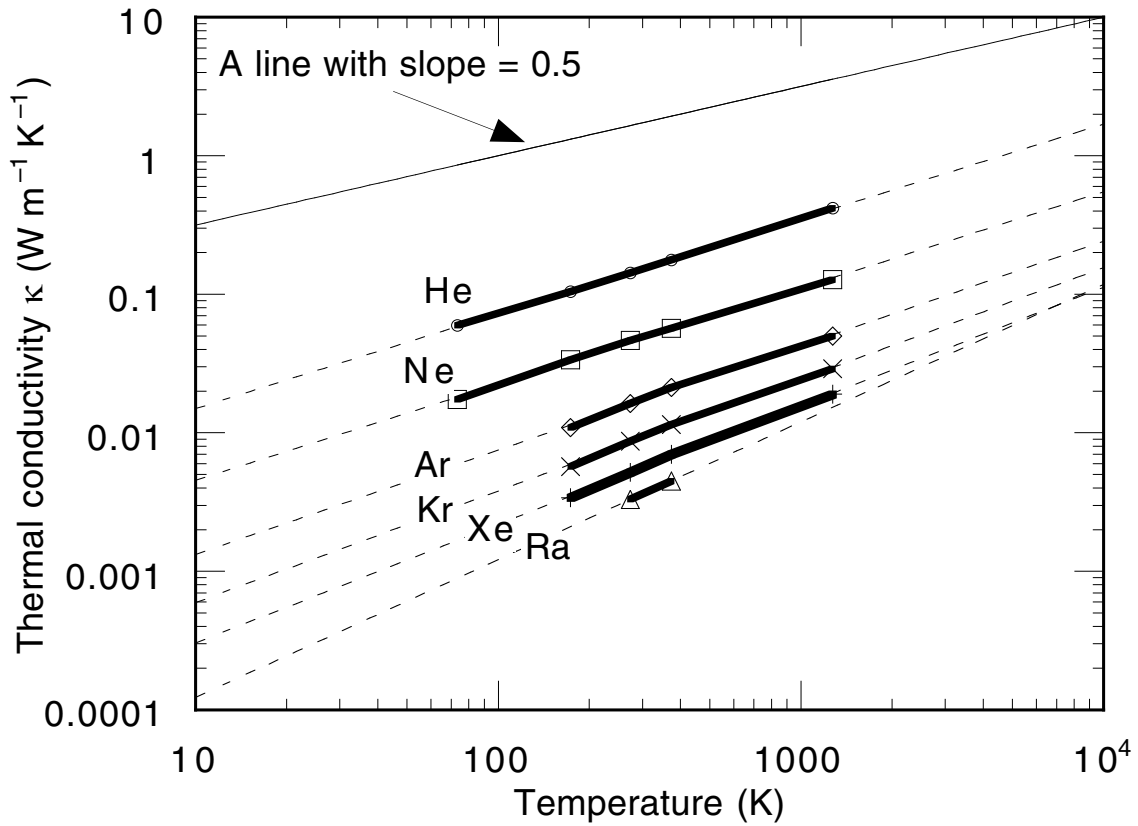
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Figure 5.20 Simplified illustration of the calculation of thermal conductivity of a gas. The figure shows three planes in the gas perpendicular to a temperature gradient. The separation of the planes is λ_{mfp} , the mean free path of the molecules. Thus molecules that are travelling in the appropriate direction in either the top or the bottom plane will (probably) cross the central plane before colliding. Energy is carried across A in both directions, but *on average* more energy flows across A from the plane in the hotter region of the gas. The analysis of the thermal conductivity centres on the problem of evaluating the net energy flow across an area A .



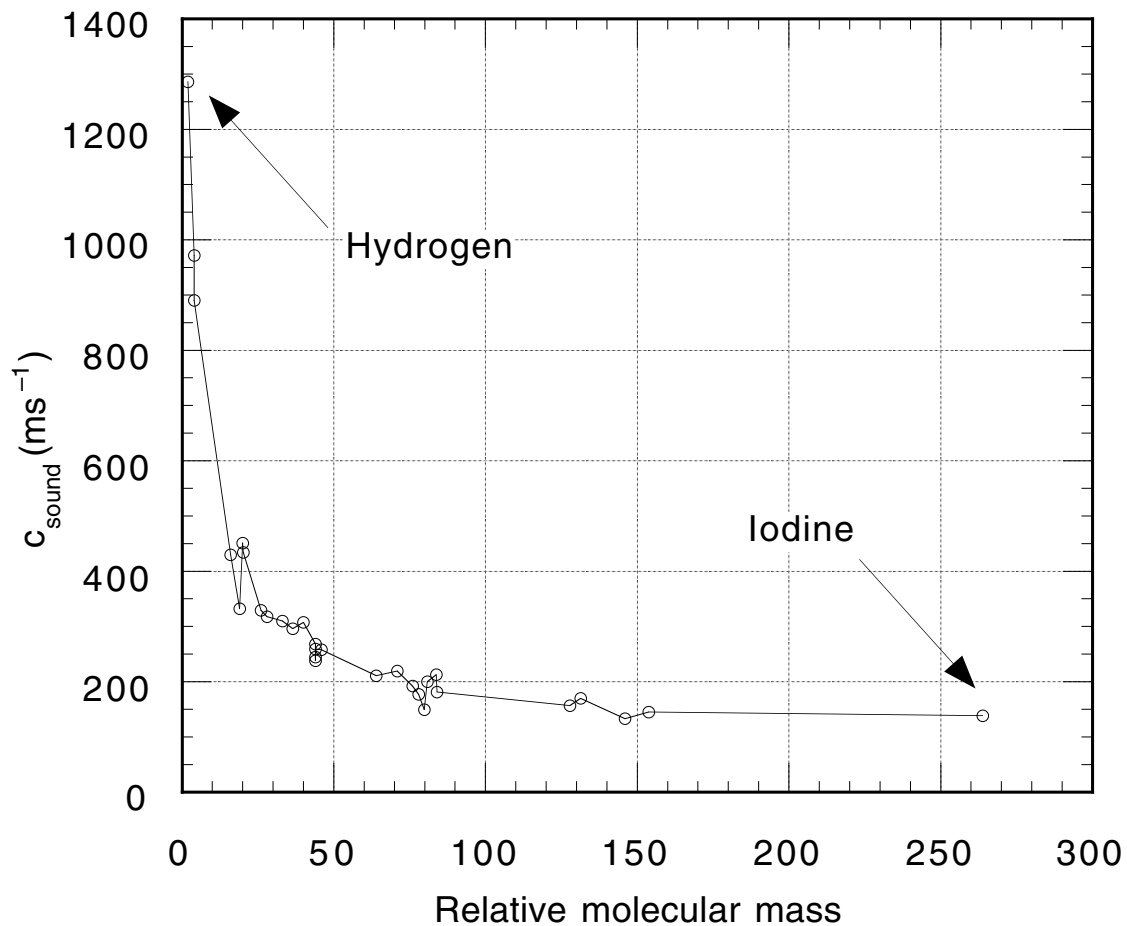
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Figure 5.21 A log–log plot of thermal conductivity κ of the monatomic gases versus temperature. Thick lines connect data points. Thin dotted lines are the best-fit lines of the form AT^x . The thin solid line illustrates what a line of slope 0.5 looks like. The parameters of the lines fitted to the data are shown in Table 5.13.



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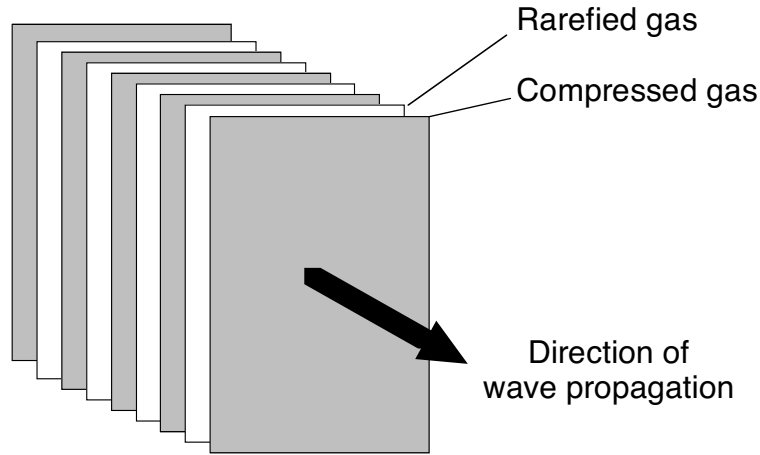
Figure 5.22. A graph of c_{sound} (ms^{-1}) versus M , the relative molecular mass (u). The graph seems to show that the molecular weight of the molecules of the gas plays a significant role in determining the velocity of sound through the gas.



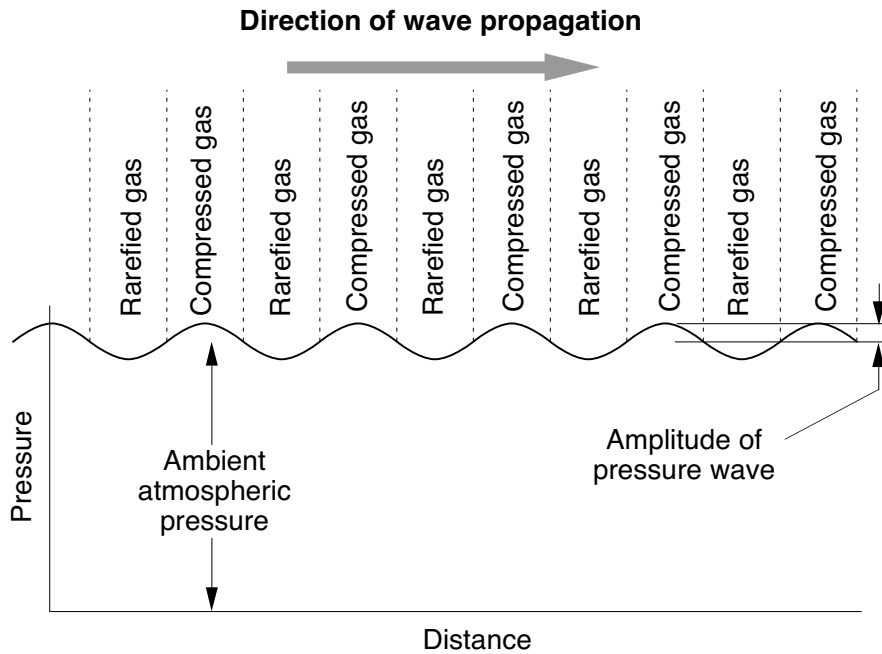
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Figure 5.23 Two illustrations of the variation of pressure within a sound wave at a given time. (a) A perspective drawing of planes of constant pressure: shaded planes represent compressed regions of the gas, un-shaded planes represent rarefied regions of gas. (b) The pressure as a function of position in a sound wave. The pressure amplitude of a sound wave rarely exceeds 1% of the ambient pressure.

(a)

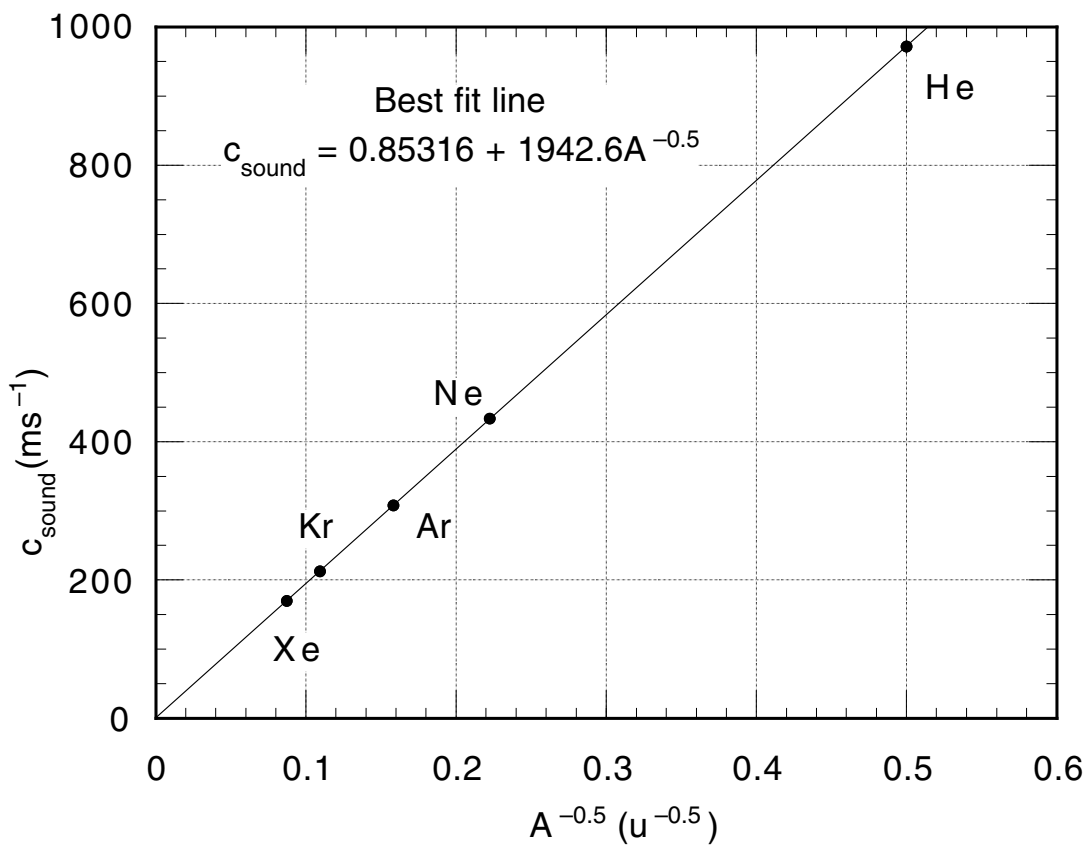


(b)



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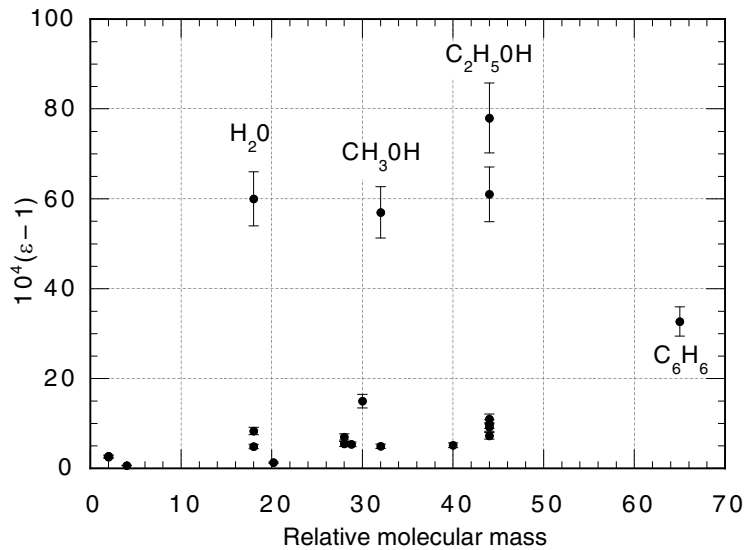
Figure 5.24. Graph of the speed of sound (m s^{-1}) versus $1/\sqrt{A}$ where A is the molecular mass in atomic mass units u . The data show a clear linear relationship as indicated by the least-squares fit shown as a line on the graph.



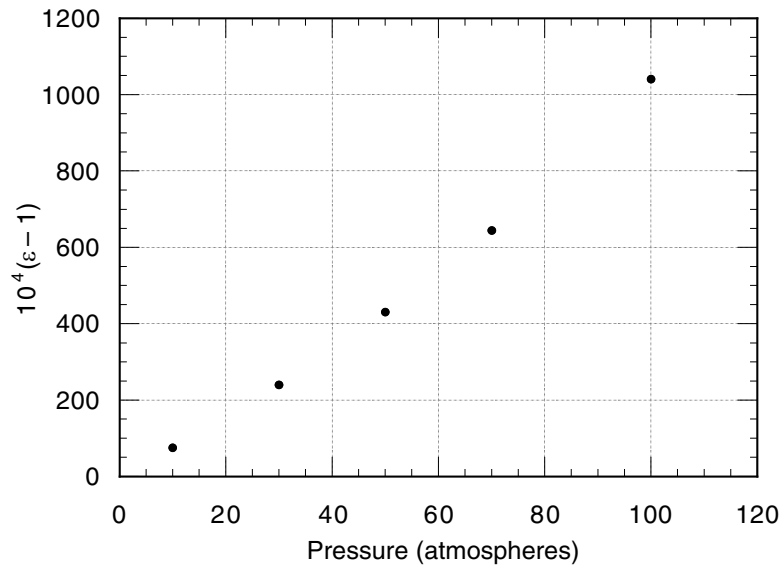
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Figure 5.25 (a) The data of Table 5.16 showing $10^4(\epsilon - 1)$ as a function of the mass of the molecules of the gas. Uncertainty indications represent $\pm 10\%$ of the values in the Table 5.16. The value for Mercury (Hg) has not been plotted because its large molecular mass distorts the scale of the graph. (b) The variation of the dielectric constant plotted as $10^4(\epsilon - 1)$ for carbon dioxide as a function of pressure at a temperature of 100°C . We see that $(\epsilon - 1)$ is depends linearly on the pressure, with a slight sign of curvature at the highest pressures.

(a)



(b)



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Figure 5.26 The effect of an applied electric field on a non-polar molecule.

Diagrams (a) and (c) refer to the situation when there is no electric field applied. In (a) the charge distribution of the electrons is symmetrically arranged around the nucleus. This is because the coulomb potential energy of an electron, which varies approximately as $1/r$ as shown in (c), is symmetric.

Diagrams (b) and (d) refer to the situation when there is an external electric field applied. In (b) the charge distribution of the electrons is now asymmetrically arranged around the nucleus. This is because the coulomb potential energy of an electron (d) is now asymmetric.

The extent of the disturbance of the charge distribution depends on the ratio of the applied electric field to the internal field. Usually this ratio is extremely small (Example 2.1).

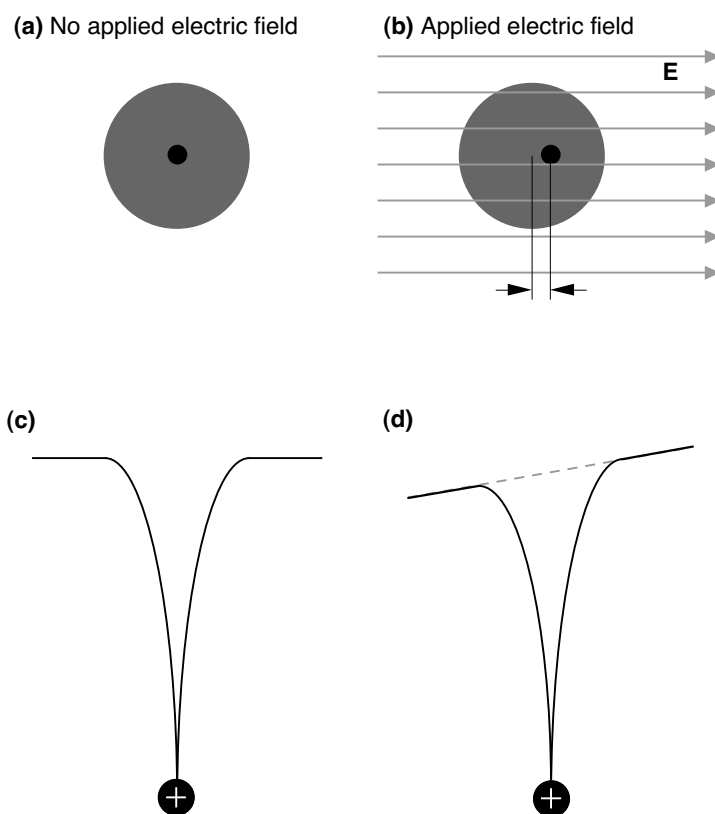
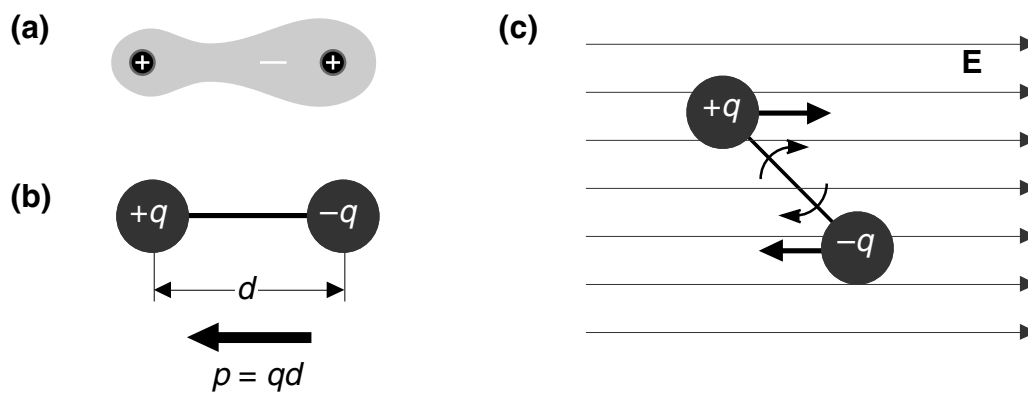
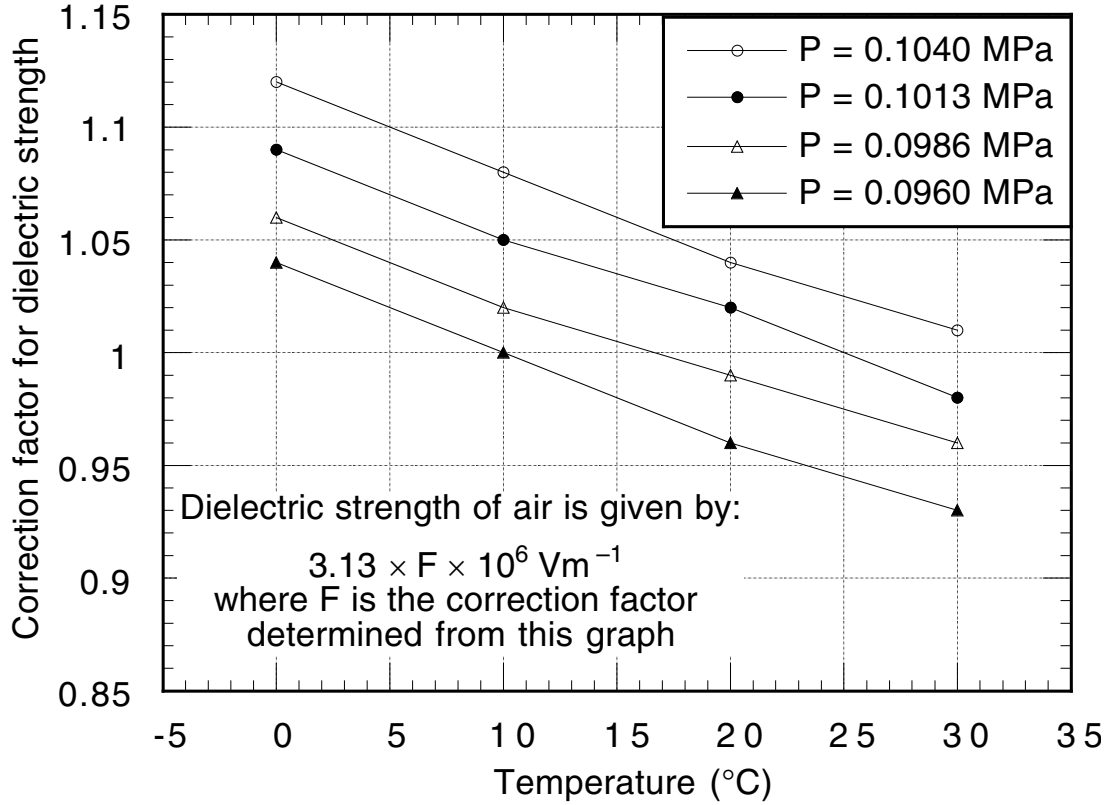


Figure 5.27 (a) Schematic illustration of a charge distribution which possesses a dipole moment. (b) For many purposes, a real molecule may be modelled as a permanent dipole moment. (c) The forces acting on a dipole moment form a torque that twists the molecule until \mathbf{p} lies parallel to \mathbf{E} .



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Figure 5.28 The variation of dielectric strength of air with temperature and pressure in the region of ambient temperature and pressure. The dielectric strength is increased at low temperatures and high pressures.



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Figure 5.29 An illustration of the pattern of light emitted when an electric current flows through a gas, called a *discharge*. The details of the pattern (1 to 5) are discussed in the text. The shaded areas in the figure represent luminous regions of the gas and the unshaded regions represent regions from which no light is emitted.

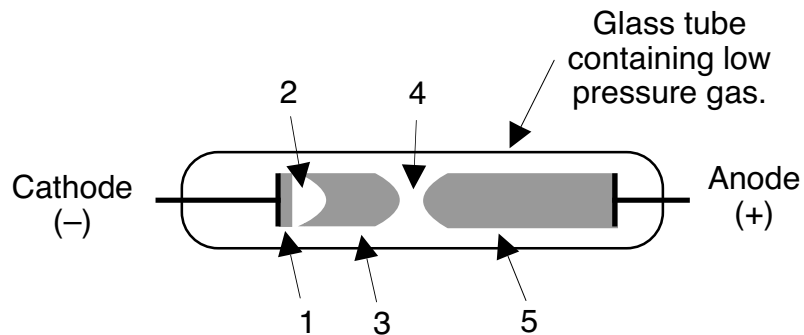
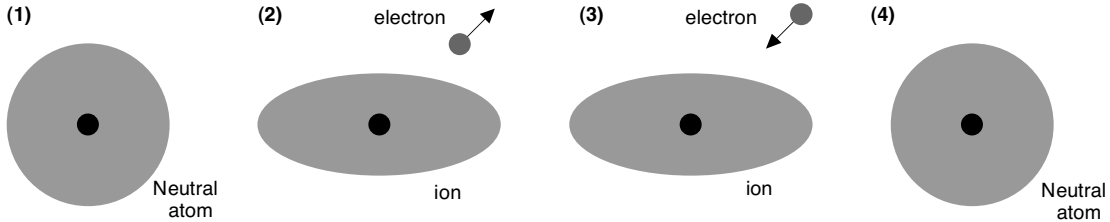
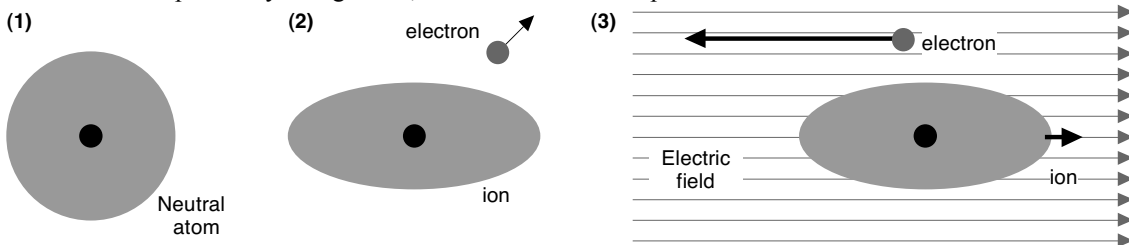


Figure 5.30 Ionisation of an atom in the absence and the presence of a strong electric field.

(a) Initially (1) we have a neutral atom, then (2) one of the causes described in the text causes an ionisation event. In the absence of an applied field the negatively-charged electron and the positively-charged ion quickly recombine (3). Finally we return to the situation (1) we started with. Thus the gas is stable against the formation of ions.

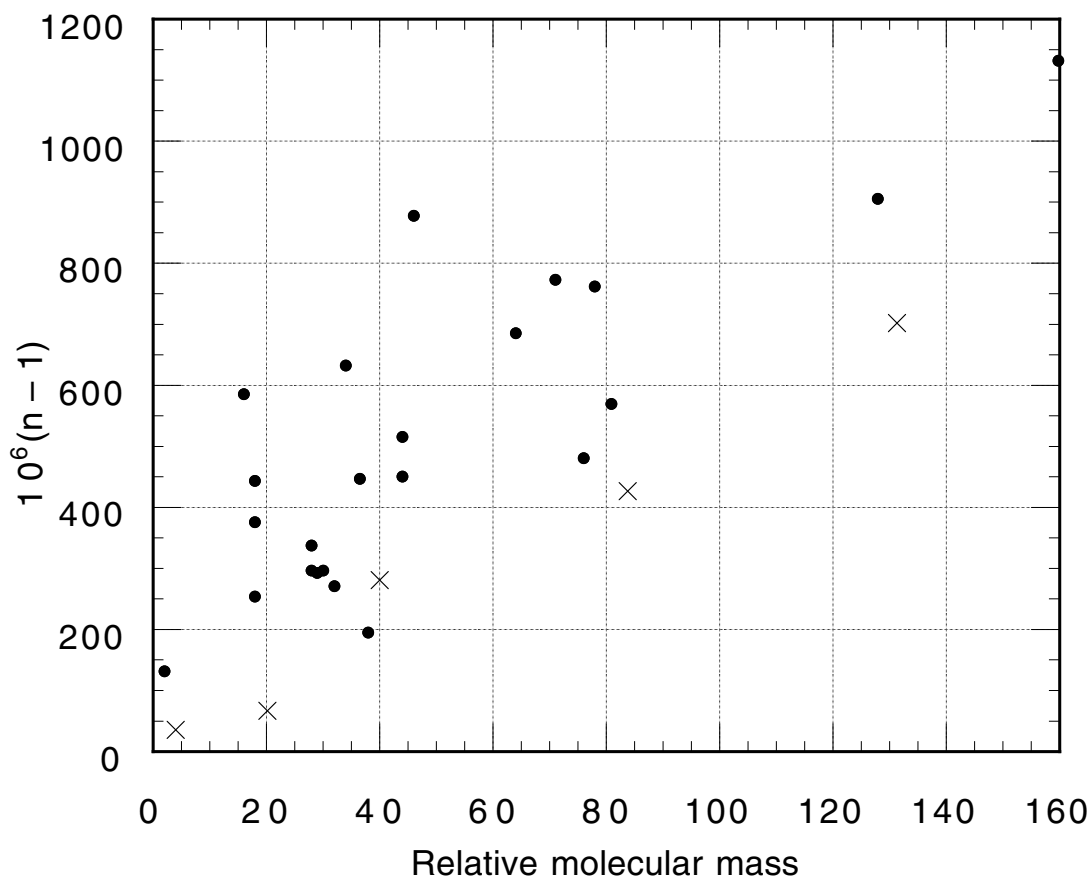


(b) Initially (1) we have a neutral atom, then (2) one of the causes described in the text causes an ionisation event. In contrast with (a), an applied electric field (3) acts to draw apart the negatively-charged electron and the positively-charged ion, and recombination is prevented.



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Figure 5.31 The refractive index n of gases from Table 5.17 plotted as a function of the relative molecular weight of the gas molecules. The refractive indices of the gases are all within 0.2 % of unity and so the quantity $10^6(n - 1)$ has been plotted so as to make visible differences in the data. The crosses (x) mark the data points for the noble gases helium, neon, argon, krypton, and xenon.



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Figure 5.32 Comparison of the wavelength of blue light with the size of an atom. Notice that in order to be clearly printed the atom has been shown at approximately 10 times its correct scale size.

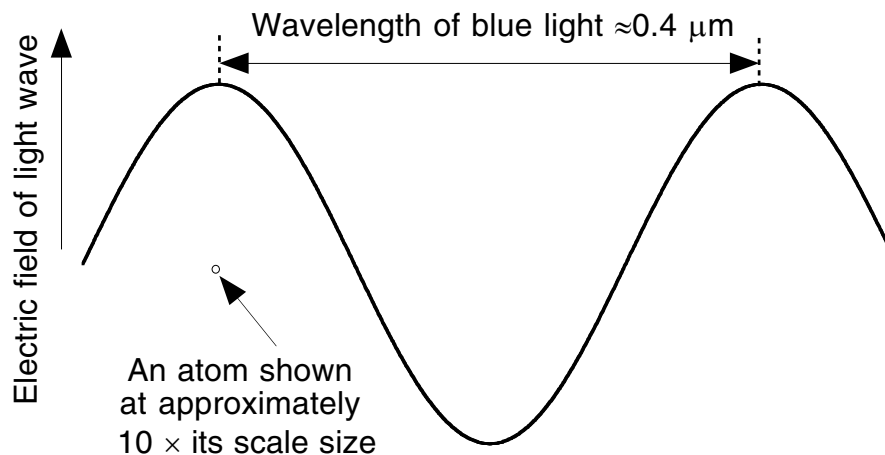
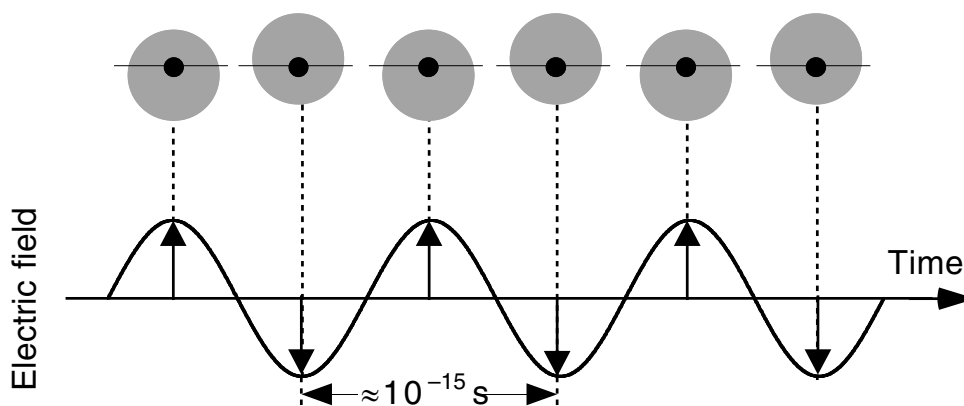
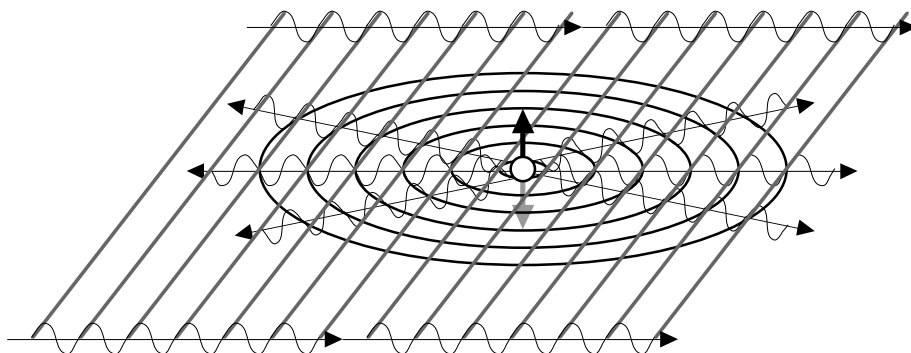


Figure 5.33 Illustration of the origin of the oscillating dipole moment on a non-polar molecule subject to an oscillating electric field. Notice that in the very short time between successive periods of the light field, only the low-mass electrons can move a significant distance. The heavy nucleus moves relatively little.



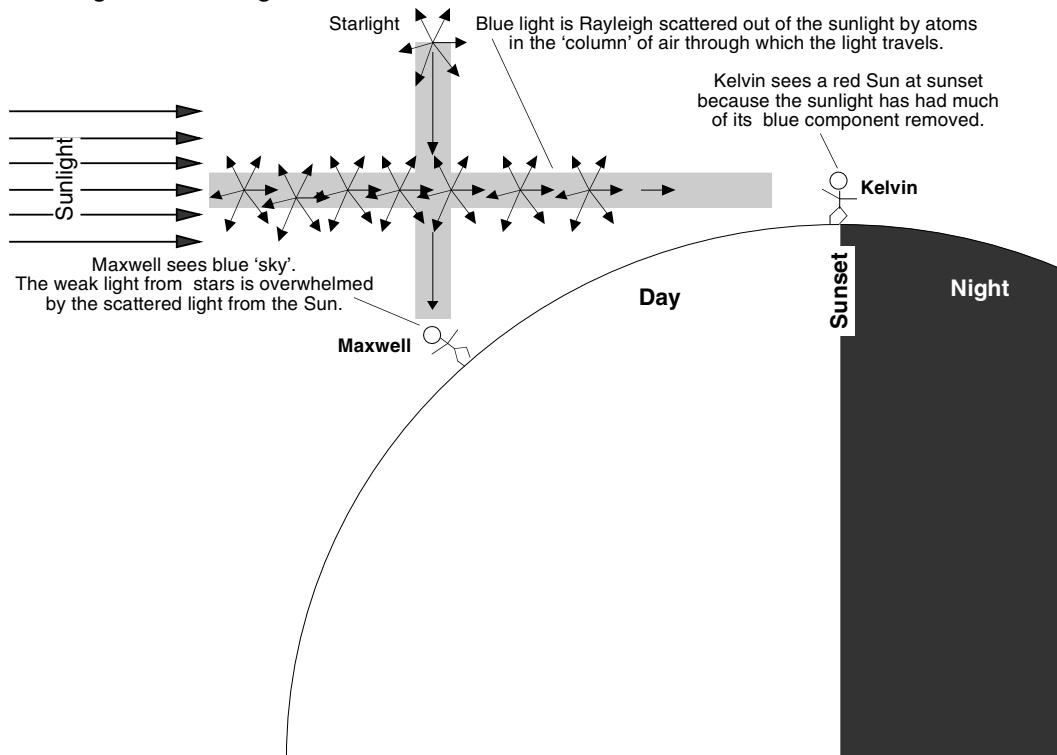
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Figure 5.34 Rayleigh scattering. An incoming plane wave causes an oscillating electric dipole moment (Figure 5.33). The oscillating dipole moment then re-radiates some of the incoming wave as a spherical wave emanating from the molecule. The figure shows a two-dimensional analogue to the scattering such as might occur with water waves on the surface of a pond.



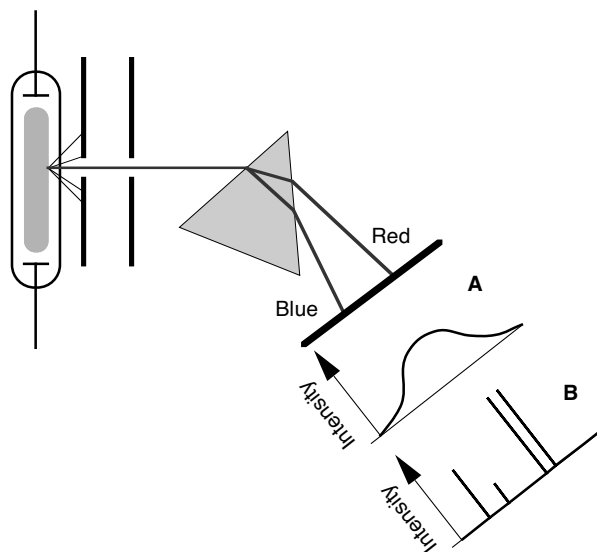
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Figure 5.35 At Kelvin's position on Earth it is sunset and the Sun appears red because the blue light has been scattered out of the sunlight to make the 'sky' appear blue for people like Maxwell. This blue light is much brighter than starlight.



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Figure 5.36 A prism spectrometer. Light is collimated by passing it through slits and then reaches a prism. The different speeds (refractive indices) of different frequencies of light through the glass of the prism (Table 7.49) causes the different colours to take different paths through the prism. The light is then projected onto a screen (or other detector). If the light is from an incandescent lamp, then the intensity varies across the screen in a way similar to that illustrated as *A*. This would look like our familiar ‘rainbow’ spectrum. However light from the positive column of a discharge tube (*B*) produces a line spectrum, and the precise positions and relative intensities of the lines are uniquely characteristic of the type of gas within the discharge tube.



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Figure 5.37 The intensity of the light emitted as function of wavelength for sodium vapour and neon gas. On each spectrum the dotted curve represents the average sensitivity of the human eye. Note that:

- The vertical axis is logarithmic and is plotted in arbitrary units.
- Only about half the lines (those with intensities greater than 300) have been plotted.
- The positive column of a sodium vapour discharge lamp appears bright yellow because of the two closely spaced intense lines (the 'D' lines) at around 589nm, close to the peak of the spectral sensitivity of the eye.
- The positive column of a neon discharge lamp appears red because of the relative scarcity of *any* intense lines near the peak of the eye's sensitivity. The intense cluster of peaks at the red of the spectrum thus dominates the appearance of the spectrum even though the eye is very insensitive in this region of the spectrum.

