CHAPTER 42
MOLECULES AND CONDENSED MATTER

**Discussion Questions**

**Q42.1** The hydrogen bond is unique to hydrogen-containing compounds because only hydrogen has a singly ionized state with no remaining electron cloud. The hydrogen ion is a bare proton and is much smaller than any singly ionized atom. It is small enough to get between two atoms, polarizing them and attracting them by means of the induced dipoles.

**Q42.2** Part of the bonding is due to electrons transferred from one atom to the other and part is due to the sharing of electrons between the atoms.

**Q42.3** $\mathrm{H}_2^+$ can't form a pair of positive and negative ions so the bonding must be covalent.

**Q42.4** The molecule stretches when it is in a higher rotational level and $I$ increases when $r$ increases. So, the $l=19 \to l=18$ transition corresponds to a larger moment of inertia.

**Q42.5** Near the bottom of the potential well the potential energy curve (Fig.42.1) of a diatomic molecule is parabolic and therefore the same as for a harmonic oscillator. But higher in the well, the well is wider than a parabola. The wider well corresponds to lower energy levels so adjacent levels move closer together as $n$ increases.

**Q42.6** For the vibrational levels the force constant is the same but the reduced mass $m_\mathrm{r}$ is double for $\mathrm{D}_2$ so the vibrational frequency $\omega$ is smaller by a factor of $1/\sqrt{2}$. The vibrational energies for $\mathrm{D}_2$ are smaller by a factor of $1/\sqrt{2}$. The equilibrium separation $r_0$ is nearly the same for $\mathrm{H}_2$ and $\mathrm{D}_2$. But $m_\mathrm{r}$ is double for $\mathrm{D}_2$ so $I$ is double. The rotational energy is proportional to $1/I$ so the rotational levels for $\mathrm{D}_2$ are smaller by a factor of 1/2.

**Q42.7** The temperature of the molecules is very low so there is very little electronic excitation and very, very few electronic energy transitions, and these are the transitions that emit visible light. The only excited levels of the molecules that are populated are low-lying rotational levels. The transition energies between these levels and the ground state are small and the photons emitted correspond to radio waves.

**Q42.8** The typical level structure is shown in Fig.42.8. The spacing between the $n=0$ and $n=1$ vibrational levels is much larger than the spacing between the lowest few rotational levels.

**Q42.9** For the lowest vibrational energy levels the energies are the same as for a harmonic oscillator. But the potential energy function $U(r)$ differs from that for an ideal spring for $r$ farther away from the equilibrium separation. And if the molecule gains enough energy the molecule can dissociate into two atoms; the "spring" can break.

**Q42.10** The outer electron charge clouds of adjacent atoms overlap significantly. Because of the electrical interactions between the electrons and because of the exclusion principle, the wave functions and energy levels are altered from their atomic values. The valence electron wave functions become less localized and extend over several atoms.

**Q42.11** A conductor has a partially filled conduction band. An insulator has an empty conduction band and a large energy gap between the empty conduction band and the filled valence band. (See Fig.42.19.)

**Q42.12** Ionic crystals have energy levels similar to those of isolated ions and absorb only certain discrete wavelengths of visible light. For metals the electrons in the partially filled conduction ban can absorb visible light of any wavelength and undergo a transition to an unfilled level in the band.

**Q42.13** The molecules move as free particles and their kinetic energy is given by $\frac{3}{2}kT$ . The energy of electrons in the conduction band of a metal depends on the Fermi energy of the band. Fig.42.23 shows that the distribution of electron states within the conduction band depends weakly on temperature.

**Q42.14** In a semiconductor there is a small energy gap between the empty conduction band and the filled valence band. Increased pressure or temperature can promote electrons into the conduction band and gives the material metallic properties.

**Q42.15** The energy levels of solid zinc are different from those of the isolated atom. The strong interaction of the atoms in the solid and the exclusion principle distort the wave functions of the electrons. The electron energies shift and form energy bands. (See Fig.42.18.)

**Q42.16** A typical electron moves so rapidly within the metal that the effect of the ions and other electrons is a uniform potential energy function. The electron-electron interactions are effectively screened due to the high density of electrons. The net charge of the ion cores and valence electrons is smoothly distributed throughout the volume of the solid and gives rise to a constant potential everywhere except at the surfaces of the solid.

**Q42.17** The nonlocalized electrons in the conduction band are free to move around and conduct both electricity and heat. The wires that conduct electricity also tend to conduct heat from the hot device.

**Q42.18** Donor atoms need to have a loosely bound valence electron outside of an electron configuration similar to that of silicon or germanium. This loosely bound electron doesn't participate in the covalent bonding when these atoms are added to silicon or germanium. An acceptor atom needs one additional electron to reach an electron configuration like that of silicon or germanium. The acceptor atom needs one more electron in order to form the same number of covalent bonds as silicon or germanium when added to those materials.

**Q42.19** Yes. Just add electrons to the surface, to fill the holes.

**Q42.20** Yes. This is explained by Fig.42.24. At low temperatures there are no electrons in the conduction band. At high temperatures a large number of electrons have enough energy to be in the conduction band.

**Q42.21** This is discussed in Section 25.2. As the temperature increases, the ions of the conductor vibrate with greater amplitude, making it more likely that a moving electron will collide with an ion. This impedes the drift of electrons through the conductor and reduces the currents. For a semiconductor, at increased temperatures electrons can gain energy from the thermal motion and move into the conduction band.

**Q42.22** Add twice as many acceptor impurity atoms as donor impurity atoms.

**Q42.23** The saturation current $I_S$ is the maximum current from $n$ to $p$ when a reverse bias voltage is applied. This current is due to free electrons in the $p$ region moving into the $n$ region. An increase in temperature increases the number of free electrons in the $p$ region.

**Q42.24** If the device is too small there isn't enough space between the source and drain to prevent electrons from tunneling through and producing a drain current even when there is no gate potential.

The device will leak current when the gate is turned off and there is not supposed to be any current.