* **10.** (II) Calculate the bond length for the NaCl molecule given that three successive wavelengths for rotational transitions are 23.1 mm, 11.6 mm, and 7.71 mm.

* **11.** (III) (*a*) Use the curve of Fig. 29–17 to estimate the stiffness constant $k$ for the $H_2$ molecule. (Recall that $\text{PE} = \frac{1}{2}kx^2$.) (*b*) Then estimate the fundamental wavelength for vibrational transitions using the classical formula (Chapter 11), but use only $\frac{1}{2}$ the mass of an H atom (because both H atoms move).

### * 29–5 Bonding in Solids

* **12.** (II) The spacing between "nearest neighbor" Na and Cl ions in a NaCl crystal is 0.24 nm. What is the spacing between two nearest neighbor Na ions?

* **13.** (II) Common salt, NaCl, has a density of $2.165\ \text{g/cm}^3$. The molecular weight of NaCl is 58.44. Estimate the distance between nearest neighbor Na and Cl ions. [*Hint*: *each* ion can be considered to have one "cube" or "cell" of side $s$ (our unknown) extending out from it.]

* **14.** (II) Repeat Problem 13 for KCl whose density is $1.99\ \text{g/cm}^3$.

### * 29–6 Band Theory of Solids

* **15.** (I) Explain on the basis of energy bands why the sodium chloride crystal is a good insulator. [*Hint*: consider the shells of $Na^+$ and $Cl^-$ ions.]

* **16.** (I) A semiconductor, bombarded with light of slowly increased frequency, begins to conduct when the wavelength of light is 640 nm. Estimate the size of the energy gap $E_g$.

* **17.** (II) Calculate the longest-wavelength photon that can cause an electron in silicon $(E_g = 1.1\ \text{eV})$ to jump from the valence band to the conduction band.

* **18.** (II) The energy gap between valence and conduction bands in germanium is 0.72 eV. What range of wavelengths can a photon have to excite an electron from the top of the valence band into the conduction band?

* **19.** (II) The energy gap $E_g$ in germanium is 0.72 eV. When used as a photon detector, roughly how many electrons can be made to jump from the valence to the conduction band by the passage of a 760-keV photon that loses all its energy in this fashion?

* **20.** (III) We saw that there are $2N$ possible electron states in the $3s$ band of Na, where $N$ is the total number of atoms. How many possible electron states are there in the (*a*) $2s$ band, (*b*) $2p$ band, and (*c*) $3p$ band? (*d*) State a general formula for the total number of possible states in any given electron band.

### * 29–7 Semiconductors and Doping

* **21.** (III) Suppose that a silicon semiconductor is doped with phosphorus so that one silicon atom in $10^6$ is replaced by a phosphorus atom. Assuming that the "extra" electron in every phosphorus atom is donated to the conduction band, by what factor is the density of conduction electrons increased? The density of silicon is $2330\ \text{kg/m}^3$, and the density of conduction electrons in pure silicon is about $10^{16}\ \text{m}^{-3}$ at room temperature.

### * 29–8 Diodes

* **22.** (I) At what wavelength will an LED radiate if made from a material with an energy gap $E_g = 1.4\ \text{eV}$?

* **23.** (I) If an LED emits light of wavelength $\lambda = 650\ \text{nm}$, what is the energy gap (in eV) between valence and conduction bands?

* **24.** (II) A silicon diode, whose current–voltage characteristics are given in Fig. 29–28, is connected in series with a battery and a 960-Ω resistor. What battery voltage is needed to produce a 12-mA current?

* **25.** (II) Suppose that the diode of Fig. 29–28 is connected in series to a 100-Ω resistor and a 2.0-V battery. What current flows in the circuit? [*Hint*: draw a line on Fig. 29–28 representing the current in the resistor as a function of the voltage across the diode. The intersection of this line with the characteristic curve will give the answer.]

* **26.** (II) Sketch the resistance as a function of current, for $V > 0$, for the diode shown in Fig. 29–28.

* **27.** (II) An ac voltage of 120 V rms is to be rectified. Estimate very roughly the average current in the output resistor $R$ $(25\ \text{k}\Omega)$ for (*a*) a half-wave rectifier (Fig. 29–29), and (*b*) a full-wave rectifier (Fig. 29–30) without capacitor.

* **28.** (III) A silicon diode passes significant current only if the forward-bias voltage exceeds about 0.6 V. Make a rough estimate of the average current in the output resistor $R$ of (*a*) a half-wave rectifier (Fig. 29–29), and (*b*) a full-wave rectifier (Fig. 29–30) without a capacitor. Assume that $R = 150\ \Omega$ in each case and that the ac voltage is 12.0 V rms in each case.

* **29.** (III) A 120-V rms 60-Hz voltage is to be rectified with a full-wave rectifier (Fig. 29–30), where $R = 21\ \text{k}\Omega$, and $C = 25\ \mu\text{F}$. (*a*) Make a rough estimate of the average current. (*b*) What happens if $C = 0.10\ \mu\text{F}$? [*Hint*: see Section 19–6.]

### * 29–9 Transistors

* **30.** (II) From Fig. 29–32, write an equation for the relationship between the base current $(I_B)$, the collector current $(I_C)$, and the emitter current ($I_E$, not labeled in the figure).

## General Problems

* **31.** Estimate the binding energy of the $H_2$ molecule by calculating the difference in kinetic energy of the electrons between when they are in separate atoms and when they are in the molecule, using the uncertainty principle. Take $\Delta x$ for the electrons in the separated atoms to be the radius of the first Bohr orbit, 0.053 nm, and for the molecule take $\Delta x$ to be the separation of the nuclei, 0.074 nm. [*Hint:* let $p \approx \Delta p_x$.]

* **32.** The average translational kinetic energy of an atom or molecule is about $\overline{\text{KE}} = \frac{3}{2}kT$ (Eq. 13–8), where $k = 1.38 \times 10^{-23}\ \text{J/K}$ is Boltzmann's constant. At what temperature $T$ will $\overline{\text{KE}}$ be on the order of the bond energy (and hence the bond likely to be broken by thermal motion) for (*a*) a covalent bond of binding energy 4.5 eV (say $H_2$), and (*b*) a "weak" hydrogen bond of binding energy 0.15 eV?