

## 7.6 The Dual Nature of Light and Matter

Light exhibits both a particle and a wave nature. De Broglie proposed that *all* matter has both a particle and a wave nature. The **de Broglie wavelength** of any particle of mass  $m$  and speed  $v$  is

$$\lambda = \frac{h}{p} = \frac{h}{mv} \quad [27.14]$$

De Broglie also proposed that the frequencies of the waves associated with particles obey the Einstein relationship  $E = hf$ .

## 7.7 The Wave Function

In the theory of **quantum mechanics**, each particle is described by a quantity  $\Psi$  called the **wave function**. The probability per unit volume of finding the particle at a particular point at some instant is proportional to  $\Psi^2$ . Quantum mechanics has been highly successful in describing the behavior of atomic and molecular systems.

## 27.8 The Uncertainty Principle

According to Heisenberg's **uncertainty principle**, it is impossible to measure simultaneously the exact position and exact momentum of a particle. If  $\Delta x$  is the uncertainty in the measured position and  $\Delta p_x$  the uncertainty in the momentum, the product  $\Delta x \Delta p_x$  is given by

$$\Delta x \Delta p_x \geq \frac{h}{4\pi} \quad [27.16]$$

Also,

$$\Delta E \Delta t \geq \frac{h}{4\pi} \quad [27.17]$$

where  $\Delta E$  is the uncertainty in the energy of the particle and  $\Delta t$  is the uncertainty in the time it takes to measure the energy.

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Do the following 4 problems (2-4, 9) 5 pts each

### MULTIPLE-CHOICE QUESTIONS

1. What is the surface temperature of a distant star having a peak wavelength of 475 nm? (a) 6 100 K (b) 5 630 K (c) 5 510 K (d) 6 350 K (e) 6 560 K
2. In a photoelectric experiment, a metal is irradiated with light of energy 3.56 eV. If a stopping potential of 1.10 V is required, what is the work function of the metal? (a) 1.83 eV (b) 2.46 eV (c) 3.20 eV (d) 4.66 eV (e) 0.644 eV
3. An electron is accelerated through a potential difference of 3.00 V before colliding with a metal target. What minimum-wavelength light can such an electron emit? (a) 204 nm (b) 352 nm (c) 414 nm (d) 536 nm (e) 612 nm
4. What is the de Broglie wavelength of an electron accelerated from rest through a potential difference of 50.0 V? (a) 0.100 nm (b) 0.174 nm (c) 0.139 nm (d) 0.834 nm (e) 0.435 nm
5. A photon scatters off an electron at an angle of  $1.80 \times 10^2^\circ$  with respect to its initial motion. What is the change in the photon's wavelength? (a) 0.002 43 nm (b) 0.243 nm (c) 0.001 72 nm (d) 0.004 85 nm (e) 0.121 nm
6. Which of the following statements are true according to the uncertainty principle? (a) It is impossible to simultaneously determine both the position and the momentum of a particle with arbitrary accuracy. (b) It is impossible to simultaneously determine both the energy and the momentum of a particle with arbitrary accuracy. (c) It is impossible to determine a particle's energy with arbitrary accuracy in a finite amount of time. (d) It is impossible to measure the position of a particle with arbitrary accuracy in a finite amount of time. (e) It is impossible to simultaneously measure both the energy and position of a particle with arbitrary accuracy.
7. The first order x-ray scattering angle of crystal A is greater than the corresponding scattering angle of crystal B for x-rays of a given energy. What can be said of the separation distance  $d_A$  of crystalline planes in crystal A as compared with the separation distance  $d_B$  in B? (a)  $d_A = d_B$  (b)  $d_A > d_B$  (c)  $d_A < d_B$  (d) The answer depends on the energy of the x-rays. (e) The answer depends on the intensity of the x-rays.
8. A proton, electron, and a helium nucleus all move at speed  $v$ . Rank their de Broglie wavelengths from longest to shortest. (a) proton, helium nucleus, electron (b) helium nucleus, proton, electron (c) proton, electron, helium nucleus (d) helium nucleus, electron, proton (e) electron, proton, helium nucleus
9. Which one of the following phenomena most clearly demonstrates the particle nature of light? (a) diffraction (b) the photoelectric effect (c) polarization (d) interference (e) refraction
10. Which one of the following phenomena most clearly demonstrates the wave nature of electrons? (a) the photoelectric effect (b) Wien's law (c) blackbody radiation (d) the Compton effect (e) diffraction of electrons by crystals