10.1 Chapter 38, Question 13.

The Andromeda galaxy is 2 million light-years from our Milky Way. Although nothing can go faster than light, it would still be possible to travel to Andromeda in much less than 2 million years. How is this possible?

**Solution** If something is travelling at an appreciable fraction of the speed of light, relativistic effects become important. Length contraction will change the space-interval between the two points.

10.2 Chapter 38, Problem 31.

A particle is moving at 0.90$c$. If its speed increases by 10%, by what factor does its momentum increase?

**Solution** A general formula for $p/p$ in terms of $u/u$ is not particularly useful, so it is easiest to evaluate the momenta in this problem directly from Equation 38-13, $p = \gamma mu$. For $u_1 = 0.9c$, $\gamma_1 = (1 - 0.81)^{-1/2} = 2.29$, and $p_1 = 2.06mc$. For $u_2 = (1 + 10\%)u_1 = 0.99c$, $\gamma_2 = 7.09$, and $p_1 = 7.02mc$. Therefore, $p_2/p_1 = 3.40$.

10.3 Chapter 38, Problem 51.

An electron moves down a 1.2-km-long particle accelerator at 0.999992$c$. In the electron’s frame, (a) how much time does the trip take and (b) how long is the accelerator?

**Solution** The accelerator’s frame is $S$ and the electron’s frame is $S'$. The same reasoning as in Problem 9 and the previous pair of problems applies to this and the next problem; that is, $\Delta t' = \Delta x'/v$ and $\Delta x' = \Delta x/\gamma$, where now $\Delta x$ and $v$ (hence also $\gamma$) are given. With a calculator of sufficient accuracy, one finds $\gamma = 1/\sqrt{1 - (0.999992)^2} = 250$, so (b) $\Delta x' = 1.2 \text{ km}/250 = 4.80 \text{ m}$, and (a) $\Delta t' = (4.80 \text{ m})/(0.999992)^{-1} \times (3 \times 10^8 \text{ m/s})^{-1} = 16.0 \text{ ns}$. Of course, since $v/c = 1 - 8 \times 10^{-6} \equiv 1 - \epsilon$, one can expand $\gamma$ in powers of $\epsilon \ll 1$ to obtain $\gamma = (2\epsilon)^{-1/2}(1 + \epsilon/4 + \cdots) \approx 1/\sqrt{2\epsilon} = 1/\sqrt{2 \times 8 \times 10^{-6}} = 250$, as before.

10.4 Chapter 39, Question 2.

Why does classical physics predict that atoms should collapse?

**Solution** Since the proton is positively charge, and the electron is negatively charged, the two particles should attract one another. Classically, there is no repulsive force to keep the proton and the electron from moving together.

10.5 Chapter 39, Question 9.

How are the wave-particle duality and the uncertainty principle related?

**Solution** It is easiest to see by considering an photon. If we consider an photon as a wave, then we clearly can’t isolate the wave to a place shorter than it’s Debroglie wavelength. However, if we consider the photon on as a particle, we recover the idea of an uncertainty in momentum (because any measurement we make will disturb the position of the photon). Thus the wave-particle duality helps to highlight the measurement issues described by the uncertainty principle.

10.6 Chapter 39, Problem 14.

Find the energy in electron-volts of (a) a 1.0-MHz radio photon, (b) a $5.0 \times 10^{14}$-Hz optical photon, and (c) a $3.0 \times 10^{18}$-Hz X-ray photon.

**Solution** From Equation 39X-6, $E_\gamma = hf$, which equals (a) $(4.136 \times 10^{-15} \text{ eV} \cdot \text{s})(1 \text{ MHz}) = 4.14 \times 10^{-9} \text{ eV}$, (b) 2.07 eV, and (c) 12.4 keV for the given frequencies.
10.7 Chapter 39, Problem 19.

Find the rate of photon production by (a) a radio antenna broadcasting 1.0 kW at 89.5 MHz, (b) a laser producing 1.0 mW of 633-nm light, and (c) an X-ray machine producing 0.10-nm X rays with a total power of 2.5 kW.

Solution The rate of photon emission is the power output (into photons) divided by the photon energy, \( \mathcal{P} / E_\gamma = \mathcal{P} / h f = \mathcal{P} \lambda / hc. \) For the devices specified, this rate is (a) \( 1 \text{ kW} / (6.626 \times 10^{-34} \text{ J}\cdot\text{s} \times 89.5 \text{ MHz}) = 1.69 \times 10^{28} \text{ s}^{-1} \), (b) \( (1 \text{ mW} \times 633 \text{ nm}) / (6.626 \times 10^{-34} \text{ J}\cdot\text{s} \times 3 \times 10^8 \text{ m/s}) = 3.18 \times 10^{15} \text{ s}^{-1} \), and (c) \( 1.26 \times 10^{18} \text{ s}^{-1} \).

10.8 Chapter 39, Problem 47.

Find the de Broglie wavelength of (a) Earth, in its 30-km/s orbital motion, and (b) an electron moving at 10 km/s.

Solution For non-relativistic momentum, Equation 39X-14 becomes \( \lambda = h / mv. \) (a) Using the values given for the Earth, one finds \( \lambda = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})(5.97 \times 10^{24} \text{ kg})^{-1}(30 \text{ km/s})^{-1} = 3.70 \times 10^{-63} \text{ m} \) (much smaller than the smallest physically meaningful distance). (b) For the given electron,

\[
\lambda = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})(9.11 \times 10^{-31} \text{ kg})^{-1}(10 \text{ km/s})^{-1} = 72.7 \text{ nm}.
\]

10.9 Chapter 39, Problem 55.

A proton is confined to a space 1 fm wide (about the size of the atomic nucleus). What is the minimum uncertainty in its velocity?

Solution From the uncertainty principle (Equation 39X-15) with \( \Delta x = 1 \text{ fm} \), \( \Delta p \sim h / \Delta x = (197.3 \text{ MeV}\cdot\text{fm}/c) / 1 \text{ fm} = 197.3 \text{ MeV}/c. \) Although this is barely small enough compared to \( mc = 938 \text{ MeV}/c \) to justify using the non-relativistic relation \( p = mv \), this is good enough for approximate purposes, so \( \Delta v = \Delta p / m \geq 197.3c / 938 = 0.21c = 6.3 \times 10^7 \text{ m/s} \).