when charging batteries (about 50%), and consumed energy to manufacture batteries may contribute likewise, in an indirect way, to energy consumption and pollution. The same is true for solar energy systems and atomic reactors (with all their problems) which need years to reach the break-even point at which energy consumption for production and emission of pollutants are compensated. In this respect, the specific energy contained in gasoline or Diesel oil (about 12,000 W·h/kg) does not look too bad. The cost per mile derived from electricity stemming from a household outlet is higher than that obtained using a Diesel engine. Moreover, Diesel engines can be made so energy efficient and pollution-reduced today that they compare quite favorably with (more expensive) hybrid automobiles (that utilize a gasoline back-up engine for recharging the battery and capture the energy, evolved from braking. This makes particularly sense for inner city traffic with frequent stop and go maneuvers). Some consideration should also be given to the distance one can drive before recharging of the battery is required which for lead-batteries is about 60 km (37 miles), and about 40–80 km (25–50 miles) for a lithium-ion battery, weighing each between 300 and 400 kg. These values are reduced in cold weather when electric heating is required. In short, matters do not look as favorable for battery-propelled cars as some proponents want us to believe (except for niche markets such as intercity delivery and utility repair trucks). This does not mean that new energy sources will not be found and used in the future (e.g. fusion). Conservation of energy and electrically propelled public transportation systems seem to be among the better alternatives. Finally, batteries are not the only available storage devices for energy, particular for smoothing out energy peaks. Among the alternative storage devices are super-capacitors (10 W·h/kg), flywheels, superconducting magnetic energy storage systems, electrolysis of water in combination with hydrogen fuel cells (1,100 W·h/kg), flow batteries, and reservoirs in which water is pumped up during off-peak hours.

Problems

1. Calculate the number of free electrons per cm^3 for gold using its density and its atomic mass.
2. Does the conductivity of an alloy change when long-range ordering takes place? Explain.
3. Calculate the time between two collisions and the mean free path for pure copper at room temperature. Discuss whether or not this result makes sense. *Hint*: Take the velocity to be the Fermi velocity, v_F, which can be calculated from the Fermi energy of copper $E_F = 7$ eV. Use otherwise classical considerations and $N_f = N_a$.
4. Electron waves are “coherently scattered” in ideal crystals at $T = 0$. What does this mean? Explain why in an ideal crystal at $T = 0$ the resistivity is small.
5. Calculate the number of free electrons per cubic centimeter (and per atom) for sodium from resistance data (relaxation time 3.1×10^{-14} s).

6. Give examples for coherent and incoherent scattering.
7. When calculating the population density of electrons for a metal by using (7.26), a value much larger than immediately expected results. Why does the result, after all, make sense? (Take $\sigma = 5 \times 10^5$ 1/Ω cm; $v_F = 10^8$ cm/s and $\tau = 3 \times 10^{-14}$ s.)
8. Solve the differential equation

$$m\frac{dv}{dt} + \frac{e\mathscr{E}}{v_F}v = e\mathscr{E} \tag{7.10}$$

   and compare your result with (7.11).
9. Consider the conductivity equation obtained from the classical electron theory. According to this equation, a bivalent metal, such as zinc, should have a larger conductivity than a monovalent metal, such as copper, because zinc has about twice as many free electrons as copper. Resolve this discrepancy by considering the quantum mechanical equation for conductivity.