Direct Current:

In metals and plasmas each atom loses at least one electron, which is relatively free to move through the system.

$$I = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t}.$$

The current is defined to flow in the same direction as the **E** field in the conductor. That is, the current is taken in the direction that a positive charge would move. In real conductors and plasmas, the moving charges are electrons, which have negative charge. Thus the electrons actually move in the opposite direction to I.

Consider a charge q moving through area A a distance $\Delta x = v_d \Delta t$. Let there be n such charges per unit volume. Then $\Delta Q = nA\Delta xq = nAv_d\Delta tq$, so we see that

$$I = nAv_d q.$$

In a typical 1 Amp current, v_d works out to around 10^{-5} m/s!

Definition of Resistance for Conductors:

$$\Delta V = IR.$$

Since R depends on the area and length of the conductor, we can factor those out to concentrate on the intrinsic conducting properties of the material:

$$R = \rho \frac{\ell}{A}.$$

The unit of R is called the Ohm so the unit of ρ is an Ohm-m. Typically for conductors ρ is from 10^{-7} to 10^{-8} Ohm-m.

The physical origin of resistance is collisions between electrons and atoms. Since temperature is a measure of average kinetic energy, it is clear that at higher temperature, the atoms (which can only do the quantum version of oscillation to increase their KE) get in the way more often, so we expect and find that ρ increases with temperature.

$$\rho = \rho_0 \left[1 + \alpha(T - T_0)\right].$$

Typically α is less than 10^{-2}/K.

Note that ℓ and A vary with T also, so the variation of R itself with T can be more complex than the variation of ρ.

Simple DC circuit: A battery and resistor!

Power loss across R must equal power gain through battery: $\mathcal{P} = I\Delta V = I^2 R = \Delta V^2/R$

Standard unit of energy for currents: Kilowatt hr = 3.6×10^6 J.

Superconductors! Superconductivity is a phenomenon of exactly zero electrical resistance, and resulting expulsion of magnetic fields, occurring in certain materials when cooled below a characteristic critical temperature. It was discovered by Dutch physicist Heike Kamerlingh Onnes on April 8, 1911. Since the original discovery it has been a major effort to understand this inherently quantum-physical phenomenon in great detail, and to find materials which superconduct at higher and higher temperatures. Typically the highest practical temperatures today are around the temperature of boiling liquid nitrogen, about 80 K.

Modern basic research in physics relies upon very large, very strong electromagnets. In all such research facilities, the magnets are superconducting, since otherwise the consumption of electric power would be impossible to pay for.

At this time— there is tremendous interest among physicists in finding materials other than silicon and germanium that are ***semiconductors***, since semiconductors are the basis of all modern electronics.

Despite intense effort not much progress has been made. Currently, a main topic of study is so-called "***topological insulators***," materials which are insulators in bulk but conduct along their boundaries.

The quest for higher temperature superconductors has also made very slow progress despite the large number of researchers involved. The ideal, of course, would be a material that is a superconductor close to the freezing point of water, with an impossible ideal being a material that superconducts at room temperature. No hint of such materials has emerged so far.