

Quiz 3: Solution

$$\Delta V = |\vec{E}| |\Delta \vec{x}| \quad \Delta PE = q\Delta V \quad KE = \frac{1}{2}mv^2 \quad F = ma \quad F = qE$$

$$e = 1.6 \times 10^{-19} \text{ [C]} \quad m_e = 9.11 \times 10^{-31} \text{ [kg]} \quad m_p = 1.67 \times 10^{-27} \text{ [kg]}$$

1. It takes $3 \times 10^6 \text{ J}$ of energy to fully recharge a 9 V battery. How many electrons must be moved across the $\Delta V = 9 \text{ V}$ potential difference to fully recharge the battery? One electron has a charge of $-e$, given above.

2×10^{24} electrons. The energy required to charge the battery is just the amount that the potential energy of all the charges changes by. Each electron is moved through 9 V, which means each electron changes its potential energy by $-e \cdot 9 \text{ V}$, where e is the charge on one electron. The total potential energy is the potential energy per electron times the number of electrons, n . Basically, this is conservation of energy: the total energy into the battery has to equal the amount of energy to move one electron across 9 V times the number of electrons.

$$\Delta E_{in} + \Delta PE = 0$$

$$3.6 \times 10^6 \text{ J} + n(-e \cdot 9 \text{ V}) = 0$$

$$ne \cdot 9 \text{ V} = 3.6 \times 10^6 \text{ J}$$

$$n = \frac{3.6 \times 10^6 \text{ J}}{e \cdot 9 \text{ V}} = \frac{3.6 \times 10^6 \text{ J}}{(1.6 \times 10^{-19} \text{ C})(9 \text{ V})} = \frac{3.6 \times 10^6}{(1.6 \times 10^{-19})(9)}$$

$$n \approx 2 \times 10^{24}$$

Here we make use of the fact that a coulomb times a volt is a joule. As usual, if you just use proper SI units throughout, the units will work out on their own.

2. An electron initially at rest is accelerated through a potential difference of 1 V, and gains kinetic energy KE_e . A proton, also initially at rest, is accelerated through a potential difference of -1 V , and gains kinetic energy KE_p . Is the electron's kinetic energy larger, smaller, or the same compared to the protons? Justify your answer. Note that the proton mass m_p is about 1000 times the electron mass m_e .

$KE_e = KE_p$. All of the potential energy gained by the proton and electron has to be converted into kinetic energy, and both particles lose the same potential energy by moving through the potential difference. Both particles have equal but opposite charges and move through equal and opposite potential differences – since the negatively charged electron moves through a positive potential difference, and the

positively charged proton moves through a negative potential difference, the net loss of potential energy $q\Delta V$ is the same. Therefore, the amount of kinetic energy gained by each particle is the same. Since both particles started at rest, their resulting kinetic energies have to be the same. The *velocity* of the electron will be much greater, however, owing to its smaller mass – recall that kinetic energy is $\frac{1}{2}mv^2$.

3. A “free” electron and a “free” proton are placed in an identical electric field. Which of the following statements are true? *Check all that apply.*

- Each particle is acted on by the same electric force and has the same acceleration.
- The electric force on the proton is greater in magnitude than the force on the electron, but in the opposite direction.
- The electric force on the proton is equal in magnitude to the force on the electron, but in the opposite direction.
- The magnitude of the acceleration of the electron is greater than that of the proton.
- Both particles have the same acceleration.

Since both particles have the same magnitude of charge $|e|$, they both feel the same electric force F_e . The forces must be in opposite directions, since protons and electrons have charges of opposite sign. However, since the electron is far lighter than the proton, it feels a much larger acceleration, $a = F_e/m$