Answer on Question #42490-Physics-Electromagnetism

An electric potential energy exists when two protons are separated by a certain distance. Does the electric potential energy increase, decrease, or remain the same (a) when both protons are replaced by electrons, and (b) when only one of the protons is replaced by an electron?

Solution

An electric potential energy exists when two protons are separated by a certain distance. It is equal to the work that must be done by an external agent to assemble the configuration. Suppose that we imagine assembling the system, one particle at a time. If there are no other charges in the region, there are no existing electric fields; therefore, no work is required to put the first proton in place. That proton, however, gives rise to an electric field that fills the region. Its magnitude at a distance r from the proton is given by equation $=\frac{ke}{r^2}$, where $+e$ is the magnitude of the charge on the proton. Since the region contains an electric field due to the first proton, there also exists an electric potential, and the external agent must do work to place the second proton at a distance d from the first proton. The electric potential energy of the final configuration is equal to the work that must be done to bring the second proton from infinity and place it at a distance d from the first proton. The electric potential at a distance d from the first proton is

$V_{\text{proton}} = +\frac{ke}{d}$. The electric potential energy of the final configuration is therefore

$$EPE = V_{\text{proton}}(+e) = +\frac{ke}{d^2}.$$

(a) If both protons are replaced by electrons, similar arguments apply. However, since the electron carries a negative charge $(-e)$, the electric potential at a distance d from the first electron is $V_{\text{electron}} = -\frac{ke}{d}$. The electric potential energy of the final configuration is now given by

$$EPE = V_{\text{electron}}(-e) = -\frac{ke}{d}(-e) = +\frac{ke}{d^2}.$$

Therefore, if both protons are replaced by electrons, the electric potential energy *remains the same*.

(b) When only one of the protons is replaced by an electron, we find that

$$EPE = V_{\text{proton}}(-e) = +\frac{ke}{d}(-e) = -\frac{ke}{d^2}.$$

Thus, when only one of the protons is replaced by an electron, the electric potential energy *decreases* from $+\frac{ke}{d^2}$ to $-\frac{ke}{d^2}$.

Answer: (a) remains the same; (b) decreases.