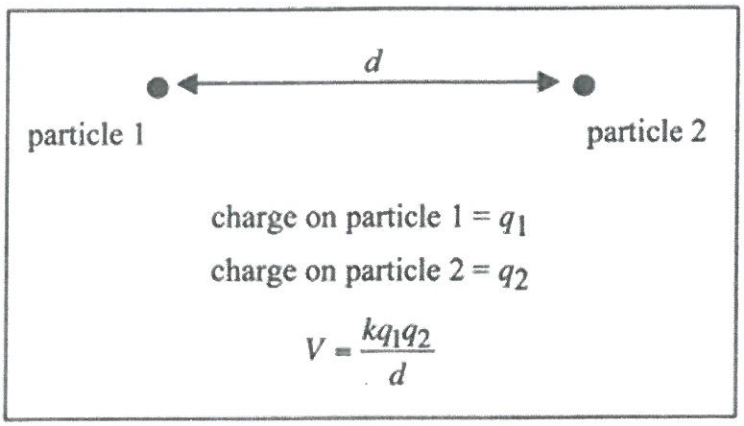
Coulombic Potential Energy

(What is attractive about Chemistry?)

Part 1: Two Charged Particles Separated by a Distance "d"



According to Coulomb, the potential energy (V) of two stationary charged particles is given by the equation above, where q_1 and q_2 are the charges on the particles (for example: -1 for an electron), d is the separation of the particles (in pm), and k is a positive-valued proportionality constant.

Critical Thinking Questions

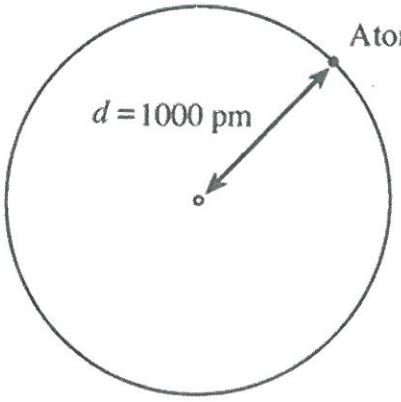
1. Assuming that q_1 and q_2 remain constant, what happens to the magnitude of V if the separation, d, is increased? it decreases
2. If the two particles are separated by an infinite distance (that is, $d = \infty$), what is the value of V? 0
3. If d is finite, and the particles have the same charge (that is, $q_1=q_2$), is $V>0$ or is $V<0$? $V > 0$
4. If q for an electron is -1,
   a) What is q for a proton? +1
   b) What is q for a neutron? 0
   c) What is q for the nucleus of a C atom? +6
5. Recall that a ^1H atom consists of a proton as the nucleus and an electron outside of the nucleus. Is the potential energy of a hydrogen atom a positive or negative number?

   negative

Part II: Ionization Energy

The ionization energy (IE) is the amount of energy needed to remove an electron from an atom and move it infinitely far away. Ionization energies are commonly measured in joules, J.

Figure 1. Ionization of a hypothetical atom L with one proton and one *stationary* electron.

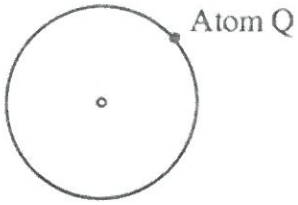


Adding 0.231×10^{-18} J to Atom L results in a base proton and a free electron.

$$IE = 0.231 \times 10^{-18}\ J$$

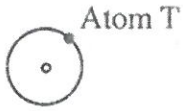
$$\text{Atom L} + 0.231 \times 10^{-18}\ J \longrightarrow p^+ + e^-$$

Figure 2. Ionization energies of two hypothetical atoms, each with one proton and one *stationary* electron separated by distance "*d*".



$d = 500$ pm

$IE = 0.462 \times 10^{-18}$ J



$d = 200$ pm

$IE = 1.16 \times 10^{-18}$ J

Table 1. Ionization energies of several hypothetical atoms, each with one proton and one stationary electron separated by distance *"d"*

Hypothetical Atom	d (pm)	IE (10^{-18} J)	V(10^{-18} J)
A	∞	0	0
E	5000.	0.0462	−0.0462
L	1000.	0.231	−0.231
Q	500.0	0.462	−0.462
T	200.0	1.16	−1.16
Z	100.0	2.31	−2.31

Critical Thinking Questions

6. Do you expect the potential energy, *V*, of the hypothetical atoms in Table 1 to be positive or negative numbers? Explain your reasoning.

Negative - all atoms contain 1 proton and 1 electron

7. Without using a calculator, predict what trend (if any) you expect for the values of *V* for these hypothetical atoms.

As "d" gets smaller V will get larger (more negative)

8. Calculate the potential energies of the hypothetical atoms to complete Table 1. Use the value $k = 2.31 \times 10^{-16}$ J·pm.

9. What is the relationship between IE and *V* for these hypothetical atoms?

$IE = -V$

10. Which of the following systems will have the larger ionization energy? Explain your reasoning.
    a. An electron at a distance of 500 pm from a nucleus with charge +2
    b. An electron at a distance of 700 pm from a nucleus with charge +2

The smaller the distance between the charges the larger the IE

11. Which of the following systems will have the larger ionization energy? Explain your reasoning.
    a. An electron at a distance d_1 from a nucleus with charge +2
    b. An electron at a distance d_1 from a nucleus with charge +1

The greater the charges the larger the IE

12. How many times larger is the larger of the two ionization energies in question 11? Show your work.

a $V = \frac{K(+2)(-1)}{d}$

b. $V = \frac{K(+1)(-1)}{d}$

a is 2 times larger than B

13. Consider a hydrogen atom and a helium ion, He^+. Which of these do you expect to have the larger ionization energy? Explain your reasoning, including any assumptions you make.

He^+ would have the larger IE

The nucleus has 2 protons so it's IE is twices as large as H

Exercises:

1. For a hypothetical atom (as in Table 1) with $V = -5.47 \times 10^{-18}$ J, what would the IE be?

IE = 5.47×10^{-18} J

2. Which of the following systems will have the larger ionization energy? Show your work.
   a. An electron at a distance d_1 from a nucleus with charge +2
   b. An electron at a distance $2d_1$ from a nucleus with charge +1

a is larger

a. $V = \frac{k(+2)(-1)}{d}$ b. $V = \frac{k(+1)(-1)}{2d}$

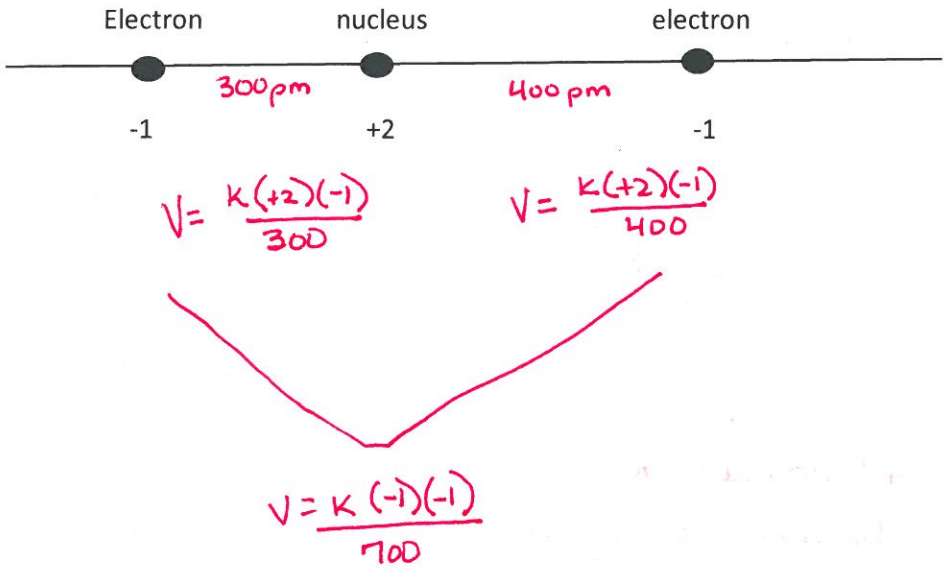
3. Which of the following systems has the larger ionization energy?
   a. An electron at a distance $5d_1$ from a nucleus with a charge +6
   b. An electron at a distance $6d_1$ from a nucleus with a charge +7

a is larger

a. $V = \frac{k(+6)(-1)}{5d}$ b. $V = \frac{k(+7)(-1)}{6d}$

4. According to the Coulombic Potential Energy equation, if a particle with a charge of -1 is *extremely* close to a particle with a charge of +2, the potential energy is: a) large and positive (b) large and negative c) small and negative d) small and positive

5. Two electrons and one helium nucleus are arranged in a straight line as shown below. The electron on the left is 300 pm from the nucleus; the electron on the right is 400 pm ~~form~~ from the nucleus. Write the *three* Coulombic Potential Energy terms ~~form~~ from this arrangement of charges.



$V = \frac{k(+2)(-1)}{300}$ $V = \frac{k(+2)(-1)}{400}$

$V = \frac{k(-1)(-1)}{700}$