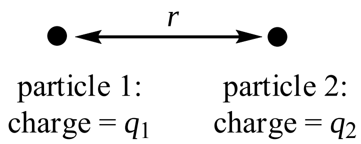
CHEM1101 Worksheet 3: The Energy Levels Of Electrons

Model 1: Two charged Particles Separated by a Distance *r*

According to Coulomb, the potential energy of two stationary particles with charges q_1 and q_2 separated by a distance r is:



$$V = k \times \frac{q_1 q_2}{r}$$

where k is a positive-valued proportionality constant.

Critical thinking questions

1. What happens to the magnitude of V if r is increased?

2. What is the value of V if the particles are separated by an infinite distance (i.e. $r = \infty$)?

3. Is $V < 0$ or is $V > 0$ if the particles have the *same* charge?

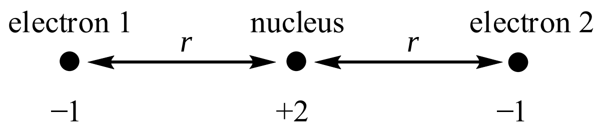
4. If $q = -1$ for an electron, what is q for a proton?

5. A hydrogen atom consists of an electron orbiting around a proton. Is the potential energy of a hydrogen atom positive or negative?

6. Using your answers to questions 2 and 5, describe in *words* what happens to the potential energy of a hydrogen atom as its electron is removed (i.e. the atom is ionized)?

7. The picture opposite shows two electrons and a helium nucleus arranged in a straight line.

   Write down the total potential energy of this arrangement as a sum of *three* terms.



Model 2: Electron Energy

For an atom, such as hydrogen, with one electron orbiting around a nucleus with charge Z, the energy of the electron is given by the equation below:

$$E_n = -(2.18 \times 10^{-18}\ \text{J})\frac{Z^2}{n^2}$$

where $n = 1, 2, 3, 4....$ The different values of n correspond to the *allowed* energies that the electron can have. These energies are called "energy levels". The lowest energy level has $n = 1$ and is called the 'ground state'. All other energy levels are called 'excited states'. The average size of the electron's orbit are also controlled by the value of n:

$$r_{\text{average}} = (0.529 \times 10^{-10}\ \text{m})\ \frac{n^2}{Z}$$

Critical thinking questions

8. The hydrogen atom has atomic number $Z = 1$. Using the equations above for the energy and average radius of electron's orbit, complete the table below for hydrogen.

n	E_n (J)	r_{average} (m)
1	-218×10^{-20}	0.529×10^{-10}
2	-54.5×10^{-20}	2.12×10^{-10}
3	-24.2×10^{-20}	
4		
5		
6		

9. The horizontal lines on the graph on the left hand side of last page of this worksheet shows the energy levels for $n = 1$, 2 and 3. Using the values you calculated for E_n, add the energy levels for $n = 4 – 6$.

10. Describe *in words* to your neighbour what happens to the energy levels and the average size of the orbit as n increases. When you have agreed on this, write down your description in a grammatically correct sentence below.

11. What do you predict is the limiting behaviour of the energy and orbit of the electron when n approaches infinity?

Model 3: Atomic Spectroscopy

The electron in a H atom wandering around in space will be in the $n = 1$ level (the "ground state"). However, if a high voltage is passed through H_2 molecules, an excited H atom is formed in which the electron is in a level with $n > 1$. The electron in this "excited" atom quickly moves ("relaxes") to a *lower* level and the excess energy is lost ("emitted") as radiation.

For example, if the excited atom is formed with its electron in the $n = 3$ level, the electron can fall into the $n = 2$ or into the $n = 1$ level. This is shown by the dotted vertical lines on the graph. The energy lost as radiation is the *difference* between the two energy levels involved: it is equal to the *length* of the dotted line.

If the electron moves from (a) $n = 3$ to $n = 1$, the energy emitted is equal to 194×10^{-20} and (b) $n = 3$ to $n = 2$, the energy emitted is equal to 30×10^{-20} J. These energies can be measured on the graph or calculated using the values in the table on question 8.

The energy of the emitted radiation for jumps (a) and (b) is shown by the horizontal lines on the graph of the right hand side overleaf.

Critical thinking questions

12. If the excited atom is formed with the electron in the $n = 4$ level, add dotted lines to the graph showing how the electron can relax.

13. For each of these jumps, work out the energy of the emitted radiation and mark it using a horizontal line on the right hand graph.

14. Repeat question 13 for an excited atom formed with the electron in the $n = 5$ level.

15. The right hand graph represents the energy of the emitted radiation for the hydrogen atom. You have drawn its "atomic spectrum".

    Light with energy *less* than 28×10^{-20} is the infrared region. Light with energy *greater* than 50×10^{-20} J is ultraviolet. Visible light lies between these values. Mark these regions on your spectrum.

16. (a) What wavelengths correspond to the upper and lower limits of visible light given in Q15?

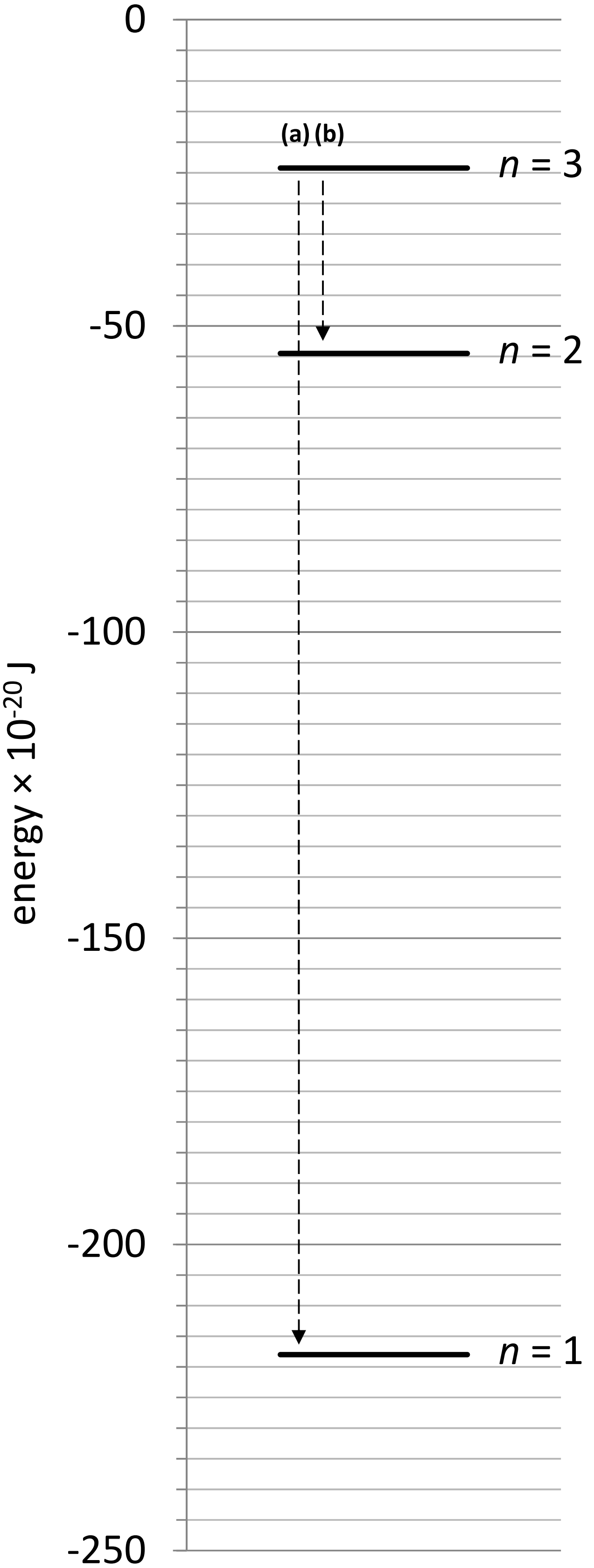
    (b) What colours correspond to these limits?

17. What do the lines in the visible part of the spectrum have in common?

18. What do the lines in the ultraviolet part of the spectrum have in common?

colour	red	orange	yellow	green	blue	indigo	violet
wavelength (nm)	660	610	580	540	470	440	410

Energy levels of the H atom



Atomic Spectrum of the H atom