

Workshop Tutorials for Introductory Physics

Solutions to QI3: Spectra

A. Review of Basic Ideas.

Spectra

A **spectroscope** is a device which uses a prism or a grating to separate light into its component wavelengths and is a valuable tool in discovering what things are made of.

Light emitted by low pressure gases contains only a **discrete** set of wavelengths, and is called a line spectrum. When atoms are excited, for example by passing a current through them in a discharge tube, their electrons will not all be in the **ground** state. Many electrons will be in **excited** states. When these electrons move from one energy state to a lower energy state they emit a **photon**.

In fact it is not really the electron which changes energy, but the whole atom, including the electron. In the same way we talk about the **gravitational** potential energy of a person increasing when they climb up stairs, but in fact it is the system, the person and the earth, which gains potential energy. Without the **Earth** there, it wouldn't mean much to talk about the person's gravitational potential energy, and without the rest of the atom there, it doesn't make sense to talk about electron energy levels either.

The **spectrum** of an element can tell us about the energy levels of that element. This **spectrum** is unique to an element, and is called an emission spectrum, because the light is **emitted** by the sample. This is used for identifying contaminants in materials such as silicon which need to be of extremely high purity to make semiconductors. A small sample of the silicon is heated until it starts emitting light, and the spectrum of this light is compared to that of pure silicon. Any extra lines indicate an **impurity**.

Another sort of spectroscopy uses the absorption of light by electrons as they move from **lower** to higher energy levels. These spectra look like a rainbow with black lines in them, and are called **absorption** spectra. Absorption spectra are used to tell what stars are made from. The hot core of a star emits a continuous spectrum of radiation. Atoms in the outer cooler region then absorb some **wavelengths**, leaving dark lines in the spectrum. This spectrum can be compared to absorption spectra for elements to find out what's in the star.

Spectroscopy is used for a vast number of applications, from monitoring blood oxygen levels to identifying contaminants. There are many other sorts of spectroscopy, which use parts of the **electromagnetic** spectrum other than the visible, and excitations of molecules as well as atoms.

B. Activity Questions:

1. Emission spectra

Some spectra, for example sunlight and incandescent globes, are approximately continuous, and you see a complete rainbow of colours. Others, like the discharge lamps, show discrete line spectra.

The spectra are different because the light sources contain different elements. In the sun, there is both absorption and emission, and many different elements. In a discharge lamp there is mainly emission.

The spectrum of any given element is unique, hence by observing the spectrum of a source, we can tell what elements are present. This is used to identify what elements are in all sorts of things, including stars.

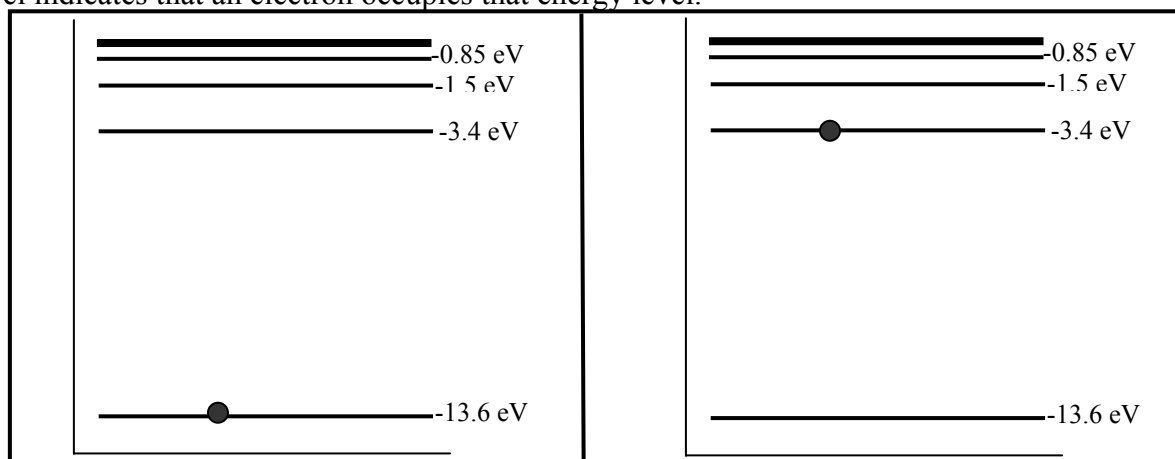
2. Identify the element

The element contained in fluorescent lights is mercury.

C. Qualitative Questions:

1. The colour of a line depends on the energy of the photons. The brightness or intensity of a line depends on the number of photons. The more often a transition happens the more photons are emitted, and the brighter the line corresponding to that transition.

2. The diagram below shows the energy levels of a hydrogen atom. A black blob drawn on an energy level indicates that an electron occupies that energy level.



- If a photon of energy 10.2 eV approaches atom A it can undergo a transition. The photon can be absorbed and the electron can jump to the next level up.
- If a photon of energy 10.2 eV approaches atom B the photon can be absorbed and the atom can be ionised. The electron would escape with the extra energy, $(10.2 - 3.4 = 6.8 \text{ eV})$ as kinetic energy.
- If a photon of energy 2 eV approaches atom A nothing will happen. This is not enough energy to excite the electron to a higher level, so the photon will not be absorbed and the atom will not become excited.
- If a photon of energy 2 eV approaches atom B nothing will happen. This is too much energy to excite the electron to the next level up, and it is not enough to go two levels up, only the exact amount of energy will excite the electron to the next level, so the photon will not be absorbed and the atom will not become excited.

D. Quantitative Question:

Consider a hydrogen atom, ^1_1H , which has one electron. In Bohr's model the electron can be in any one of many discrete energy levels. An electron in the ground state ($n=1$) energy level of hydrogen has an energy of -13.6eV , and in general $E_n = -13.6\text{eV}/n^2$.

a. see diagram opposite.

b. The violet lines have the highest energy and the red has the lowest.

c. The red has the lowest energy, hence it must be due to a transition from $n = 3$ to $n = 2$, which is an energy of $E = -1.5 - -3.4 = 1.9 \text{ eV} = 3.0 \times 10^{-19}\text{J}$. The frequency is then $f = E/h = 3.0 \times 10^{-19}\text{J} / 6.63 \times 10^{-34} \text{ J.s} = 4.6 \times 10^{14} \text{ s}^{-1}$.

Which is a wavelength of

$$\lambda = c/f = 3 \times 10^8 \text{ m.s}^{-1} / 4.6 \times 10^{14} \text{ s}^{-1} = 650 \text{ nm}.$$

d. Transitions from $n > 1$ to $n=1$ have greater energy than the visible lines, hence they are in the UV part of the spectrum.

e. The shortest wavelength possible corresponds to the highest energy possible, which is from $n = \infty$, with energy 0 eV to $n = 1$, with -13.6 eV , a change of $13.6 \text{ eV} = 2.18 \times 10^{-18}\text{J}$.

$$\text{Again using } f = E/h = 2.18 \times 10^{-18}\text{J} / 6.63 \times 10^{-34} \text{ J.s} = 3.28 \times 10^{15} \text{ s}^{-1}$$

Which has a wavelength of $\lambda = c/f = 3 \times 10^8 \text{ m.s}^{-1} / 3.28 \times 10^{15} \text{ s}^{-1} = 91\text{nm}$. This is in the ultraviolet region.

