On fluorescent lamps ANSWERS

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The passage below, the fact file and questions 1, 3, 4, 5, 7 and 8 are taken or adapted from *Advanced Questions on Everyday Physics* by Susan Williams.

Lightbulbs have come a long way since the first discharge tubes were invented by William Crookes in 1870. He passed an electric discharge through gases at low pressure and found that the colour of the discharge seen depended on the gas in the tube. Such discharges gave rise to line spectra when the light was passed through a diffraction grating or a prism.

The first fluorescent lamps used either mercury vapour which gave a bluish light or sodium lamps which gave a yellow light. The latter had the advantage that they produced improved illumination in fog, but had the disadvantage that all colours except yellow looked different shades of grey. People walking home at night looked terrible. It really wasn't acceptable and modern fluorescent lights have coatings inside which absorb some of the initial radiation from the gas in the lamp and reradiate it at different frequencies to give a light closer to the continuous spectrum from the Sun.

Now compact fluorescent lamps are being used instead of ordinary lightbiulbs in the home with energy saving advantages.

Fact File
$E_2 - E_1 = hf$, where E_2 and E_1 are electron energy levels in an atom and hf is the energy of the emitted photon.
$h = 6.63 \times 10^{-34}\,\mathrm{J\,s}$
$c = 3.0 \times 10^{8}\,\mathrm{m\,s^{-1}}$
$1\,\mathrm{eV} = 1.60 \times 10^{-19}\,\mathrm{J}$

Warm-up problems

1. Describe how the characteristic colours arise in the excited gases in the discharge tubes in terms of electrons within the atom and line spectra.

   - electrons within the atom can be given energy and this is called excitation
   - electrons in an atom can only exist at definite/discrete energy levels/orbits
   - these particular levels depend on the particular atom, being characteristic of it
   - an electron falls from one level to another
   - photon emitted
   - photon has definite wavelength, related to the difference in energy levels
   - thus the pattern of particular wavelengths emitted—the line spectrum—has colours unique to that element

2. What is meant by *ionization*, *excitation* and *de-excitation*?
Ionization is when an electron gains so much energy that it is no longer bound to the nucleus of an atom (within the potential well of the electric field surrounding the nucleus) Its total energy becomes positive, and it becomes free of the atom.
Excitation occurs when an electron moves to a higher energy level.
De-excitation is when an electron, having been excited, returns to a lower level again.

3. Describe how the coatings worked in terms of energy levels and excitation.
Ultra violet light is converted to visible light by the phosphor coatings on the inside of the glass tube of a fluorescent lamp. Molecules of the phosphor absorb an ultra-violet photon, thus undergoing excitation, and this means they undergo a big jump up in energy level (UV photons are quite energetic). At some later time, they fall down the energy levels by a lesser amount, emitting their energy as a photon of visible light in the process.

Regular problems

4. Why did the early sodium lamps give such peculiar lighting, and *why were these these lamps good fog lamps rather than ordinary lighting?
The early sodium lights gave a yellow light, due to the yellow lines in the spectrum of sodium. Therefore, things will not look the same under this fairly monochromatic illumination (the frequencies needed for us to observe all colours other than this particular yellow were missing). However, it is rather good in foggy conditions, since all the radiation is emitted quite near to the peak sensitivity of the human eye (this is how yellow-tinted glasses work for low-light conditions), and also light of one colour will penetrate fog with a minimum of dispersion effects (which tend to split light up into its component colours). The light also tends not to be scattered as much by fog particles as light from a higher frequency or mixed frequency source.

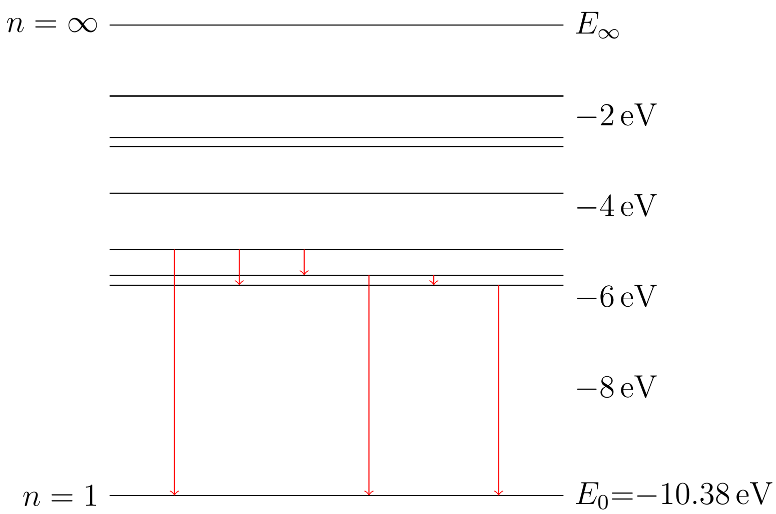
5. The wavelengths of visible light emitted from a hydrogen lamp are 656 nm, 486 nm, 434 nm and 410 nm.

   (a) What photons energies do these correspond to?

$$\begin{aligned} E(\lambda) &= \frac{hc}{\lambda} \\ E(656\,\mathrm{nm}) &= 3.03\times10^{-19}\,\mathrm{J} \\ E(434\,\mathrm{nm}) &= 4.58\times10^{-19}\,\mathrm{J} \\ E(656\,\mathrm{nm}) &= 4.84\times10^{-19}\,\mathrm{J} \end{aligned}$$

   (b) If they are all due to electron jumps down to the second energy level in the hydrogen atom at -3.4 eV, calculate the next four energy levels in eV.
   The photon energies in eV are 1.90, 2.55, 2.86 and 3.03, so the next four energy levels will be 12.1 eV, 12.8 eV, 13.1 eV and 13.2 eV.

6. The diagram below shows the energy levels of mercury.



(a) Estimate the energy needed to excite the atom from the ground state to the highest energy level shown in the diagram.
The highest energy level seems to have energy of around $-1.6\,\text{eV}$ and the ground state has energy of around $-10.4\,\text{eV}$, so the energy needed to go from the ground state to the highest state is $-1.6\,\text{eV} - (-10.4\,\text{eV}) = 8.8\,\text{eV}$.

(b) Mercury atoms in an excited state at $-4.95\,\text{eV}$ can de-excite directly or indirectly to the ground state. Show that the photons released could have six different energies.
(See arrows on diagram, showing the possible de-excitation transitions.)

(c) The lowest energy photons from the previous part have wavelengths of $5.65\,\mu\text{m}$. Use this to calculate the energy difference between the two closely spaced levels.

$$
\begin{aligned}
E(\lambda) &= \frac{hc}{\lambda} \\
E(5.65\,\mu\text{m}) &= 3.52 \times 10^{-20}\,\text{J} \\
&= 0.22\,\text{eV},
\end{aligned}
$$

which looks to agree with the diagram.

WOTAN DELUX BULBS
Brightness 11W
Power consumption 20%
Lamp life 8000 h
Not dimmable
11W 240–250 V 50/60 Hz

7. (a) How much energy would be saved in a week if the modern lightbulb shown was on for 4 hr every night instead of an ordinary bulb giving the same illumination?
Energy for Wotan bulb $= 11\,\text{W} \times 4\,\text{hr/day} \times 3600\,\text{s/hr} \times 7\,\text{day/week} = 1.1\,\text{MJ/week}$,
Energy for ordinary bulb $= 60\,\text{W} \times 4\,\text{hr/day} \times 3600\,\text{s/hr} \times 7\,\text{day/week} = 6.1\,\text{MJ/week}$,
Energy saved $= 5.0\,\text{MJ/week}$.

(b) Why does this bulb have such a low power consumption compared to an ordinary bulb?
Heat losses from a filament lamp are reduced by using a fluorescent tube.

Extension problems

8. (a) Calculate the energy in eV of photons of sodium light of wavelength 590 nm.
   Photon energy $= \frac{hc}{\lambda}$, giving 3.37×10^{-19} J or 2.1 eV.

   (b) *If the distance travelled by electrons in the sodium lamp between collisions is 1.0×10^{-4} m, calculate the electric field strength needed to cause the emission of sodium light.

   HINT: Electric field strength is measured in $\mathrm{V\,m^{-1}}$. Consider the definition of the electron volt, and what 'voltage' (i.e. field potential) the electron must move through between collisions to gain enough energy to cause another atom to emit a photon of light.

   Electric field strength $= \frac{V}{d} = \frac{2.1\,\mathrm{V}}{1.0 \times 10^{-4}\,\mathrm{m}} = 2.1 \times 10^{4}\,\mathrm{V\,m^{-1}}$.

   (c) **What would happen to the electric field strength needed if the gas were at a higher pressure?
   Higher pressure would give a shorter mean distance between molecules so a higher field strength will be needed.

9. (a) If you encounter a puddle on a rainy day with a thin layer of oil on its surface, you might see some rainbow patterns. How do these arise?
   The colours in the oil film are due to thin film interference. Briefly, light reflected from the first surface interferes with the light reflected from the second surface. Whether ther interference is constructive or destructive depends on the wavelength of the light, the refractive index of the film, and the path length of the light inside the film. The thickness of the film varies across the puddle surface, and so as it thickens, the interference gives progressively longer wavelength colours for those experiencing constructive interference in reflexion.

   (b) What pattern would you expect to see if you observe the same puddle at night time, lit only be a (sodium) street lamp?
   With monochromatic light, there is no progressive constructive interference for different wavelengths, as for this single wavelength, we are going to see either constructive of destructive intereference. Thus, we will get light and dark bands, rather than a rainbow of colours. Look out for this on the next rainy night in puddles near a street lamp!