CHAPTER 12

Optical Phenomena And Properties Of Matter

CONTENTS

August 27, 2021

1 INTRODUCTION

Many people are using solar power as a source of energy for their homes. Solar power can be used to heat water or to supply electricity. Have you ever noticed solar panels on homes and buildings? Have you ever wondered how solar energy is converted to electrical energy? In this chapter, we examine the process that is used to achieve this energy conversion.

Figure 1: The use of solar cells to supply electricity.

2 THE PHOTOELECTRIC EFFECT

Around the turn of the twentieth century, it was observed by a number of physicists (including Hertz, Thomson and Von Lenard) that when light was shone onto a metal plate, electrons were emitted by the metal. This is called the photoelectric effect. (photo for light, electric for the electron.)

The characteristics of the photoelectric effect were a surprise and a very important development in modern Physics. To understand why it was a surprise we need to look at the history to understand what physicists were expecting to happen and then understand the implications for Physics going forward.

2.1 History and expectations as to the photoelectric effect

In 1887, Heinrich Hertz (a German physicist) noticed that ultraviolet light incident on a metal plate could cause sparks. Metals were known to be good conductors of electricity, because the electrons are more able to move. They should be able to be dislodged if energy were added through the incident light. The problem was that different metals requred different minimum frequencies of light.

The expectation at the time was that electrons would be emitted for any frequency of light, after a delay (for low intensities) during which the electrons absorbed sufficient energy to escape from the metal surface. The higher the intensity the shorter the delay was be as they would absorb energy faster. This was based on the idea that light was a wave continuously delivering energy to the electrons.

It is important to remember that higher frequency light corresponds to higher energy.

The next piece of the puzzle came from Philipp Lenard (a Hungarian physicist) in 1902 when he discovered that the maximum velocity with which electrons are ejected by ultraviolet light is entirely independent of the intensity of light.

His expectation was that at high intensities the electrons would absorb more energy and so would have a greater velocity.

A **paradox** existed as the expectations and the observations did not match.

Albert Einstein (a German physicist) solved this paradox by proposing that light is made up of packets of energy called quanta (now called photons) which interacted with the electrons in the metal like particles instead of waves. Each incident photon would transfer all its energy to one electron in the metal.

DEFINITION

The photoelectric effect

The photoelectric effect is the process whereby an electron is emitted by a substance when light shines on it.

Einstein received the 1921 Nobel Prize for his contribution to understanding the photoelectric effect. His explanation wasn't very popular and took a while to be accepted, in fact, some scientists at the time felt that is was a big mistake.

In the motivation letter for Einstein to be accepted into the Prussian Academy of Science it was specifically mentioned as a mistake:

> In sum, one can say that there is hardly one among the great problems in which modern physics is so rich to which Einstein has not made a remarkable contribution. That he may sometimes have missed the targeting his speculations, as, for example, in his hypothesis of light-quanta, cannot really be held too much against him, for it is not possible to introduce really new ideas even in the most exact sciences without sometimes taking a risk - A. Pais, "Subtle is the Lord: The Science and the Life of Albert Einstein," New York: Oxford University Press, 1982, p. 382

2.2 Implications of Einstein's model

Einstein's model is consistent with the observation that the electrons were emitted immediately when light was shone on the metal and that the *intensity* of the light made *no difference* to the maximum kinetic energy of the emitted electrons.

The energy needed to knock an electron out of the substance is called the **work function** (symbol W_0) of the substance. This is a characteristic of the substance. If the energy of the photon is less than the work function then no electron can be emitted, no matter how many photons strike the substance. We know that the frequency of light is related to the energy, that is why there is a minimum frequency of light that can eject electrons. This minimum frequency we call the cut-off frequency, f_0. For a specific colour of light (i.e. a certain frequency or wavelength), the energy of the photons is given by $E = hf = \frac{hc}{\lambda}$, where h is Planck's constant. This tells us that the $W_0 = hf_0$.

DEFINITION

Work function

The minimum energy needed to knock an electron out of a metal is called the **work function** (symbol W_0) of the metal. As it is energy, it measured in joules (J).

Energy is conserved so if the photon has a higher energy than W_0 then the excess energy goes into the kinetic energy E_k of the electron that was emitted from the substance.

The excess over and above the binding energy is actually the **maximum** kinetic energy the emitted electron can have. This is because not all electrons are on the surface of the substance. For electrons below the surface there is additional energy required to eject the electron from the material which then cannot contribute to the kinetic energy of the electron.

$$E = W_0 + E_{k\,\text{max}}$$

$$E_{k\,\text{max}} = hf - W_0$$

This equation is known as the photoelectric equation.

The last piece of the puzzle is now clear, the question was 'why does increasing the intensity of the light not affect the maximum kinetic energy of the emitted photons?'. The answer is that each emitted electron has absorbed **one** photon, increasing the intensity just increases the number of photons (we expect more electrons but we don't expect their maximum kinetic energy to change).

The discovery and understanding of the photoelectric effect was one of the major breakthroughs in science in the twentieth century as it provided concrete evidence of the particle nature of light. It overturned previously held views that light was composed purely of a continuous transverse wave. On the one hand, the wave nature is a good description of phenomena such as diffraction and interference for light, and on the other hand, the photoelectric effect demonstrates the particle nature of light. This is now known as the 'dual-nature' of light. (dual means two)

Einstein won the 1921 Nobel Prize for Physics for this quantum theory and his explanation of the photoelectric effect.

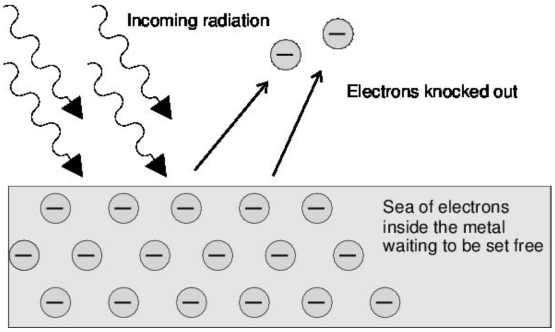


Figure 2: The photoelectric effect: Incoming photons on the left hit the electrons inside the metal surface. The electrons absorb the energy from the photons, and are ejected from the metal surface.

We can observe this effect in the following practical demonstration of photoelectric emission. A zinc plate is charged negatively and placed onto the cap of an electroscope. In Figure 3, red light is shone onto the zinc plate. There is no change observed even if the intensity (brightness) of the red light is increased. In Figure 4, ultraviolet light of low intensity is shone onto the zinc and it is observed that the leaf of the electroscope collapse. This allows us to conclude that the negative charge on the plate decreased as electrons were ejected from the metal when the ultraviolet light was incident on the plate.

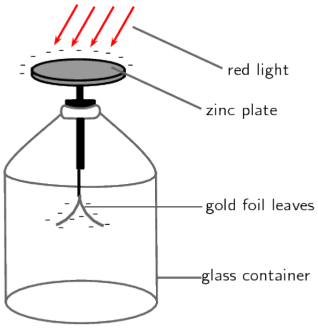


Figure 3: Red light incident on the zinc plate of an electroscope.

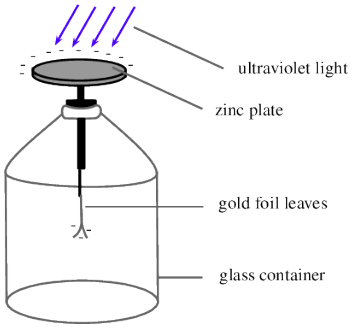


Figure 4: Ultraviolet light incident on the zinc plate of an electroscope.

The work function is different for different elements. The smaller the work function, the easier it is for electrons to be emitted from the metal. Metals with low work functions make good conductors. This is because the electrons are attached less strongly to their surroundings and can move more easily through these materials. This reduces the resistance of the material to the flow of current i.e. it conducts well. Table 1 shows the work functions for a range of elements.

Element	Work Function (J)
Aluminium	$6,9 \times 10^{-19}$
Beryllium	$8,0 \times 10^{-19}$
Calcium	$4,6 \times 10^{-19}$
Copper	$7,5 \times 10^{-19}$
Gold	$8,2 \times 10^{-19}$
Lead	$6,9 \times 10^{-19}$
Silicon	$1,8 \times 10^{-19}$
Silver	$6,9 \times 10^{-19}$
Sodium	$3,7 \times 10^{-19}$

Table 1: Work functions of selected elements determined from the photoelectric effect. (From the Handbook of Chemistry and Physics.)

2.3 Units of energy

When dealing with calculations at a small scale (like at the level of electrons) it is more convenient to use different units for energy rather than the joule (J). We define a unit called the electron-volt (eV) as the kinetic energy gained by an electron passing through a potential difference of one volt.

$$E = q \times V$$

where q is the charge of the electron and V is the potential difference applied. The charge of 1 electron is $1,6 \times 10^{-19}\ C$, so $1\ eV$ is calculated to be:

$$1eV = (1,6 \times 10^{-19}C \times 1V = 1,6 \times 10^{-19}J$$

You can see that $1,6 \times 10^{-19}J$ is a very small amount of energy and so using electron-volts (eV) at this level is easier.

Hence, $1\ eV = 1,6 \times 10^{-19}J$which means that $1J = 6,241 \times 10^{18}eV$

ACTIVITY

Demonstration of the photoelectric effect

We can set up an experiment similar to the one used originally to study the photoelectric effect. The experiment allows us to measure the number of electrons emitted and the maximum kinetic energy of the ejected electrons.

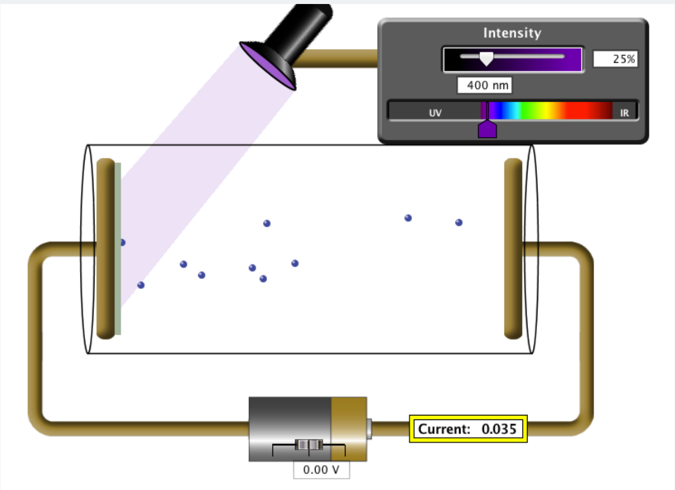


Figure 5: Photoelectric effect apparatus

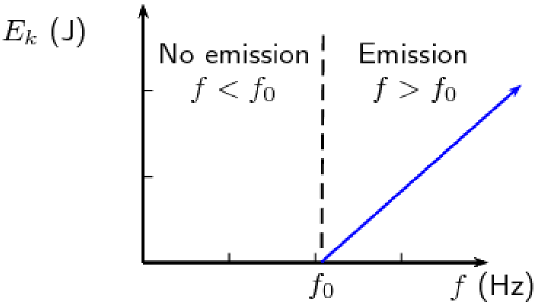
In the diagram of the Photoelectric Effect Apparatus, an ammeter allows for a current to be measured. Measuring the current allows us to deduce information about the number of electrons emitted and the kinetic energy of the ejected electrons.

In the diagram, notice that the potential difference supplied by the battery is zero and yet a current is still measured on the ammeter. This is due to the incoming photons having sufficient frequency and hence energy greater than the work function to eject electrons. The ejected electrons travel across the evacuated space and allow for a current to be measured in the circuit.

Remember, photon energy is related to frequency while intensity is related to the number of photons.

2.4 Using the photoelectric effect equation

It is useful to observe the photoelectric effect equation represented graphically.



It can be seen from the graph that E_k is plotted on the y–axis and f is plotted on the x–axis. Using the straight line equation, $y = mx + c$, we can identify

$$E_{k\,\text{max}} = hf - W_0$$

$$\underbrace{E_{k\,\text{max}}}_{y} = h\underbrace{\ f\ }_{x} - hf_0$$

This allows us to conclude that the slope of the graph m is Planck's constant h. Also, the x intercept is the cut-off frequency f_0.

WORKED EXAMPLE 1: THE PHOTOELECTRIC EFFECT USING SILVER

QUESTION

Ultraviolet radiation with a wavelength of 250 nm is incident on a silver foil (work function $W_0 = 6,9 \times 10^{-19}$ J). What is the maximum kinetic energy of the emitted electrons?

SOLUTION

Step 1: Determine what is required and how to approach the problem

We need to determine the maximum kinetic energy of an electron ejected from a silver foil by ultraviolet radiation.

The photoelectric effect tells us that:

$$E_{k\,\text{max}} = E_{\text{photon}} - W_0$$
$$E_{k\,\text{max}} = h\frac{c}{\lambda} - W_0$$

We also have:

- Work function of silver: $W_{0_{silver}} = 6,9 \times 10^{-19}\ J$
- UV radiation wavelength = $250\ nm = 250 \times 10^{-9}\ m = 2,50 \times 10^{-7}\ m$
- Planck's constant: $h = 6,63 \times 10^{-34}\ m^2 \cdot kg \cdot s^{-1}$
- Speed of light: $c = 3 \times 10^{8}\ m \cdot s^{-1}$

Step 2: Solve the problem

$$\begin{aligned} E_k &= \frac{hc}{\lambda} - W_{0\ \text{silver}} \\ &= \left[6,63 \times 10^{-34} \times \frac{3 \times 10^{8}}{2,5 \times 10^{-7}}\right] - 6,9 \times 10^{-19} \\ &= 1,06 \times 10^{-19}\ \text{J} \end{aligned}$$

The maximum kinetic energy of the emitted electron will be $1,06 \times 10^{-19}\ J$.

WORKED EXAMPLE 2: THE PHOTOELECTRIC EFFECT USING GOLD

QUESTION

If we were to shine the same ultraviolet radiation ($f = 1,2 \times 10^{15}$ Hz) on a gold foil (work function = $8,2 \times 10^{-19}$ J) would any electrons be emitted from the surface of the gold foil?

SOLUTION

Step 1: Calculate the energy of the incident photons

For the electrons to be emitted from the surface, the energy of each photon needs to be greater than the work function of the material.

$$\begin{aligned} E_{\text{photon}} &= hf \\ &= 6,63 \times 10^{-34} \times 1,2 \times 10^{15} \\ &= 7,96 \times 10^{-19} \text{ J} \end{aligned}$$

Therefore each photon of ultraviolet light has an energy of $7,96 \times 10^{-19}$ J.

Step 2: Write down the work function for gold.

$$W_{0 \text{ gold}} = 8,92 \times 10^{-19} \text{ J}$$

Step 3: Is the energy of the photons greater or smaller than the work function?

$$\begin{gathered} 7,96 \times 10^{-19} \text{ J} < 8,92 \times 10^{-19} \text{ J} \\ E_{\text{photons}} < W_{0 \text{ gold}} \end{gathered}$$

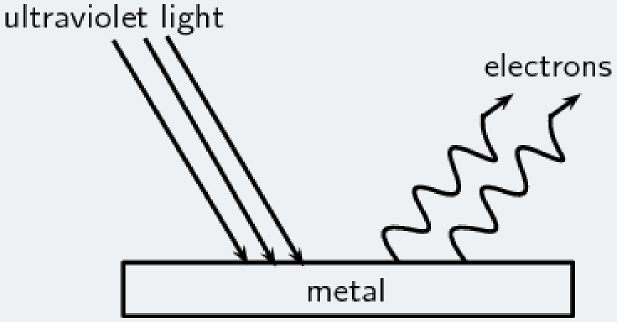
Since the energy of each photon is less than the work function of gold, the photons do not have enough energy to knock electrons out of the gold. No electrons would be emitted from the gold foil.

WORKED EXAMPLE 3: NSC 2011 PAPER 1

QUESTION

A metal surface is illuminated with ultraviolet light of wavelength 330 nm. Electrons are emitted from the metal surface.

The minimum amount of energy required to emit an electron from the surface of this metal is $3,5 \times 10^{-19}$ J.



1. Name the phenomenon illustrated above. (1 mark)
2. Give ONE word or term for the underlined sentence in the above paragraph. (1 mark)
3. Calculate the frequency of the ultraviolet light. (4 marks)
4. Calculate the kinetic energy of a photoelectron emitted from the surface of the metal when the ultraviolet light shines on it. (4 marks)
5. The intensity of the ultraviolet light illuminating the metal is now increased. What effect will this change have on the following:
    5.1. Kinetic energy of the emitted photoelectrons (Write down only INCREASES, DECREASES or REMAINS THE SAME.) (1 mark)
    5.2. Number of photoelectrons emitted per second (Write down only INCREASES, DECREASES or REMAINS THE SAME.) (1 mark)
6. Overexposure to sunlight causes damage to skin cells.
    6.1. Which type of radiation in sunlight is said to be primarily responsible for this damage? (1 mark)
    6.2. Name the property of this radiation responsible for the damage. (1 mark)

[TOTAL: 14 marks]

WORKED EXAMPLE 3: NSC 2011 PAPER 1 (CONTINUED)

SOLUTION

Question 1

Photo-electric effect

(1 mark)

Question 2

Work function

(1 mark)

Question 3

$$\begin{aligned} c &= f\lambda \\ 3 \times 10^{8} &= f(330 \times 10^{-9}) \\ \therefore f &= 9,09 \times 10^{14} \text{ Hz} \end{aligned}$$

OR

$$\begin{aligned} E &= \frac{hc}{\lambda} \\ &= \frac{(6,63 \times 10^{-34})(3 \times 10^{8})}{(330 \times 10^{-9})} \\ &= 6,03 \times 10^{-19} \text{ J} \end{aligned}$$

$$\begin{aligned} E &= hf \\ 6,03 \times 10^{-19} \text{ J} &= (6,63 \times 10^{-34})f \\ \therefore f &= 9,09 \times 10^{14} \text{ Hz} \end{aligned}$$

(4 marks)

Question 4

Option 1:

$$\begin{aligned} E &= W_o + K \\ \frac{hc}{\lambda} &= W_o + K \\ \therefore \frac{(6,63 \times 10^{-34})(3 \times 10^{8})}{330 \times 10^{-9}} &= 3,5 \times 10^{-19} + K \\ \therefore K &= 2,53 \times 10^{-19} \text{ J} \end{aligned}$$

WORKED EXAMPLE 3: NSC 2011 PAPER 1 (CONTINUED)

Question 4

Option 2:

$$\begin{aligned} E &= W_o + K \\ hf &= W_o + K \\ \therefore (6,63 \times 10^{-34})(9,09 \times 10^{14} &= 3,5 \times 10^{-19} + K \\ \therefore K &= 2,53 \times 10^{-19} \text{ J} \end{aligned}$$

(4 marks)

Question 5.1

Remains the same.

(1 mark)

Question 5.2

Increases

(1 mark)

Question 6.1

Ultraviolet radiation

(1 mark)

Question 6.2

High energy or high frequency

(1 mark)

[TOTAL: 12 marks]

2.5 Solar cells

The generation of electricity using solar cells isn't due to the photoelectric effect but is similar in nature. Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.

Electrons (negatively charged) are knocked loose from their atoms, allowing them to flow through the material to produce electricity. This is called the photovoltaic effect. The photovoltaic effect was first observed by French physicist Antoine E. Becquerel in 1839.

Due to the special composition of solar cells, the electrons are only allowed to move in a single direction. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.

3 EMISSION AND ABSORPTION SPECTRA

3.1 Emission spectra

You have learnt previously about the structure of an atom. The electrons surrounding the atomic nucleus are arranged in a series of levels of increasing energy. Each element has a unique number of electrons in a unique configuration therefore each element has its own distinct set of energy levels. This arrangement of energy levels serves as the atom's unique fingerprint.

In the early 1900s, scientists found that a liquid or solid heated to high temperatures would give off a broad range of colours of light. However, a gas heated to similar temperatures would emit light only at certain specific wavelengths (colours). The reason for this observation was not understood at the time.

Scientists studied this effect using a discharge tube.

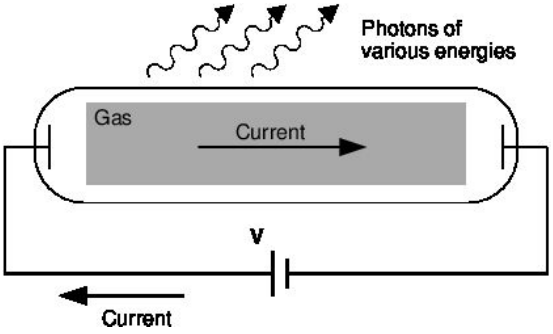


Figure 6: Diagram of a discharge tube. The tube is filled with a gas. When a high enough voltage is applied across the tube, the gas ionises and acts like a conductor, allowing a current to flow through the circuit. The current excites the atoms of the ionised gas. When the atoms fall back to their ground state, they emit photons to carry off the excess energy.

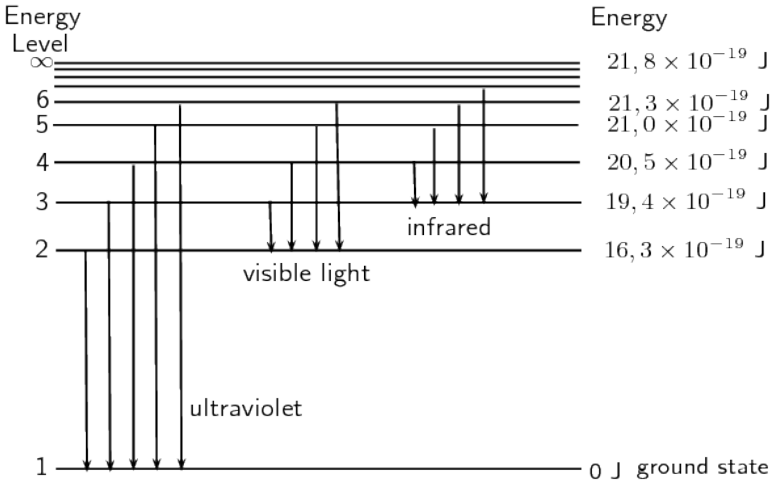
A discharge tube (shown in Figure 6) is a gas-filled, glass tube with a metal plate at both ends. If a large enough voltage difference is applied between the two metal plates, the gas atoms inside the tube will absorb enough energy to make some of their electrons come off, i.e. the gas atoms are ionised. These electrons start moving through the gas and create a current, which raises some electrons in other atoms to higher energy levels. Then as the electrons in the atoms fall back down, they emit electromagnetic radiation (light). The amount of light emitted at different wavelengths, called the **emission spectrum**, is shown for a discharge tube filled with hydrogen gas in Figure 7 below. Only certain wavelengths (i.e. colours) of light are seen, as shown by the lines in the picture.

Figure 7: Diagram of the emission spectrum of hydrogen in the visible spectrum. Four lines are visible, and are labelled with their wavelengths. The three lines in the $400–500nm$ range are in the blue part of the spectrum, while the higher line ($656nm$) is in the red/orange part.

Eventually, scientists realised that these lines come from photons of a specific energy, emitted by electrons making transitions between specific energy levels of the atom. Figure 8 shows an example of this happening. When an electron in an atom falls from a higher energy level to a lower energy level, it emits a photon to carry off the extra energy. This photon's energy is equal to the energy difference between the two energy levels (ΔE).

$$\Delta E_{\text{electron}} = E_f - E_i$$

As we previously discussed, the frequency of a photon is related to its energy through the equation $E = hf$. Since a specific photon frequency (or wavelength) gives us a specific colour, we can see how each coloured line is associated with a specific transition.



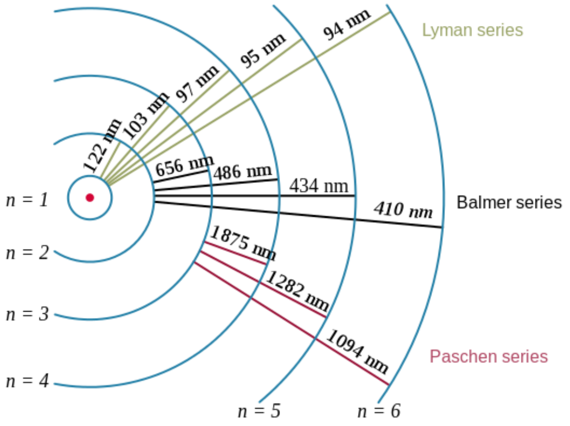


Figure 8: In the first diagram are shown some of the electron energy levels for the hydrogen atom. The arrows show the electron transitions from higher energy levels to lower energy levels. The energies of the emitted photons are the same as the energy difference between two energy levels. You can think of absorption as the opposite process. The arrows would point upwards and the electrons would jump up to higher levels when they absorb a photon of the right energy. The second representation shows the wavelengths of the light that is emitted for the the various transitions. The transistions are grouped into a series based on the lowest level involved in the transition.

Visible light is not the only kind of electromagnetic radiation emitted. More energetic or less energetic transitions can produce ultraviolet or infrared radiation. However, because each atom has its own distinct set of energy levels (its fingerprint!), each atom has its own distinct emission spectrum.

3.2 Absorption spectra

Atoms do not only emit photons; they also absorb photons. If a photon hits an atom and the energy of the photon is the same as the gap between two electron energy levels in the atom, then the electron in the lower energy level can absorb the photon and jump up to the higher energy level. If the photon energy does not correspond to the difference between two energy levels then the photon will not be absorbed (it can still be scattered).

Using this effect, if we have a source of photons of various energies we can obtain the **absorption spectra** for different materials. To get an absorption spectrum, just shine white light on a sample of the material that you are interested in. White light is made up of all the different wavelengths of visible light put together. In the absorption spectrum there will be gaps. The gaps correspond to energies (wavelengths) for which there is a corresponding difference in energy levels for the particular element.

The absorbed photons show up as black lines because the photons of these wavelengths have been absorbed and do not show up. Because of this, the absorption spectrum is the exact inverse of the emission spectrum.

Look at the two figures below. In Figure 9 you can see the line emission spectrum of hydrogen. Figure 10 shows the absorption spectrum. It is the exact opposite of the emission spectrum! Both emission and absorption techniques can be used to get the same information about the energy levels of an atom.

Figure 9: Emission spectrum of Hydrogen.

Figure 10: Absorption spectrum of Hydrogen.

The dark lines correspond to the frequencies of light that have been absorbed by the gas. As the photons of light are absorbed by electrons, the electrons move into higher energy levels. This is the opposite process of emission.

The dark lines, absorption lines, correspond to the frequencies of the emission spectrum of the same element. The amount of energy absorbed by the electron to move into a higher level is the same as the amount of energy released when returning to the original energy level.

WORKED EXAMPLE 4: ABSORPTION

QUESTION

I have an unknown gas in a glass container. I shine a bright white light through one side of the container and measure the spectrum of transmitted light. I notice that there is a black line (*absorption* line) in the middle of the visible red band at 642 nm. I have a hunch that the gas might be hydrogen. If I am correct, between which 2 energy levels does this transition occur? (Hint: look at Figure 8 and the transitions which are in the visible part of the spectrum.)

SOLUTION

Step 1: What is given and what needs to be done?

We have an absorption line at 642 nm. This means that the substance in the glass container absorbed photons with a wavelength of 642 nm. We need to calculate which 2 energy levels of hydrogen this transition would correspond to. Therefore we need to know what energy the absorbed photons had.

Step 2: Calculate the energy of the absorbed photons

$$\begin{aligned} E &= \frac{hc}{\lambda} \\ &= \frac{\left(6,63 \times 10^{-34}\right) \times \left(3 \times 10^{8}\right)}{642 \times 10^{-9}} \\ &= 3,1 \times 10^{-19} \text{ J} \end{aligned}$$

The absorbed photons had an energy of $3,1 \times 10^{-19}$ J.

Step 3: Find the energy of the transitions resulting in radiation at visible wavelengths

Figure 8 shows various energy level transitions. The transitions related to visible wavelengths are marked as the transitions beginning or ending on Energy Level 2. Let us find the energy of those transitions and compare with the energy of the absorbed photons we have just calculated.

Energy of transition (absorption) from Energy Level 2 to Energy Level 3:

$$\begin{aligned} \Delta E_{electron} = E_{2,3} &= E_2 - E_3 \\ &= 16,3 \times 10^{-19} - 19,4 \times 10^{-19} \\ &= -3,1 \times 10^{-19} \text{ J} \end{aligned}$$

Therefore the energy of the photon that an electron must absorb to jump from Energy Level 2 to Energy Level 3 is $3,1 \times 10^{-19}$ J. (NOTE: The minus sign means that absorption is occurring.)

This is the same energy as the photons which were absorbed by the gas in the container! Therefore, since the transitions of all elements are unique, we can say that the gas in the container is hydrogen. The transition is absorption of a photon between Energy Level 2 and Energy Level 3.

3.3 Applications of emission and absorption spectra

The study of spectra from stars and galaxies in astronomy is i called spectroscopy. Spectroscopy is a tool widely used in astronomy to learn different things about astronomical objects.

3.3.1 Identifying elements in astronomical objects using their spectra

Measuring the spectrum of light from a star can tell astronomers what the star is made of. Since each element emits or absorbs light only at particular wavelengths, astronomers can identify what elements are in the stars from the lines in their spectra. From studying the spectra of many stars we know that there are many different types of stars which contain different elements and in different amounts.

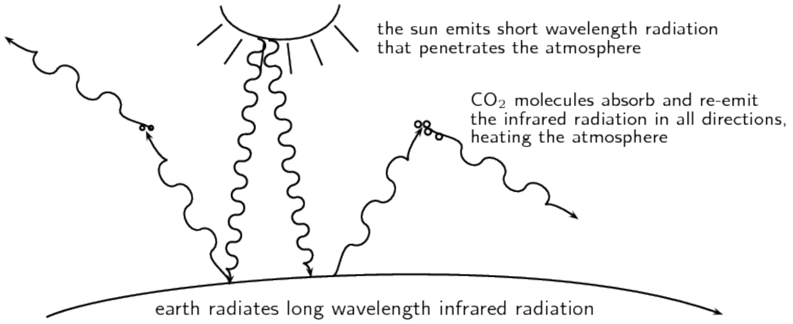
3.3.2 Determining velocities of galaxies using spectroscopy

You have already learnt in Chapter 9 about the Doppler effect and how the frequency (and wavelength) of sound waves changes depending on whether the object emitting the sound is moving towards or away from you. The same thing happens to electromagnetic radiation (light). If the object emitting the light is moving towards us, then the wavelength of the light appears shorter (called **blue-shifted**). If the object is moving away from us, then the wavelength of its light appears stretched out (called **red-shifted**).

The Doppler effect affects the spectra of objects in space depending on their motion relative to us on the earth. For example, the light from a distant galaxy that is moving away from us at some velocity will appear red-shifted. This means that the emission and absorption lines in the galaxy's spectrum will be shifted to a longer wavelength (lower frequency). Knowing where each line in the spectrum would normally be if the galaxy was not moving and comparing it to the red-shifted position, allows astronomers to precisely measure the velocity of the galaxy relative to the Earth.

3.3.3 Global warming and greenhouse gases

The sun emits radiation (light) over a range of wavelengths that are mainly in the visible part of the spectrum. Radiation at these wavelengths passes through the gases of the atmosphere to warm the land and the oceans below. The warm earth then radiates this heat at longer infrared wavelengths. Carbon dioxide (one of the main greenhouse gases) in the atmosphere has energy levels that correspond to the infrared wavelengths that allow it to absorb the infrared radiation. It then also emits at infrared wavelengths in all directions. This effect stops a large amount of the infrared radiation from getting out of the atmosphere, which causes the atmosphere and the earth to heat up. More radiation is coming in than is getting back out.



So increasing the amount of greenhouse gases in the atmosphere increases the amount of trapped infrared radiation and therefore the overall temperature of the earth. The earth is a very sensitive and complicated system upon which life depends and changing the delicate balances of temperature and atmospheric gas content may have disastrous consequences if we are not careful.

4 CHAPTER SUMMARY

- The photoelectric effect is the process whereby an electron is emitted by a substance when light shines on it.
- A substance has a work function which is the minimum energy needed to emit an electron from the metal. The frequency of light whose photons correspond exactly to the work function is known as the cut-off frequency.

$$E = W_0 + E_{k\,\text{max}}$$
$$E_{k\,\text{max}} = hf - W_0$$

- The number of electrons ejected increases with the intensity of the incident light.
- The photoelectric effect illustrates the particle nature of light and establishes the quantum theory.
- Emission spectra are formed when certain frequencies of light are emitted by a gas, as a result of electrons in the atoms dropping from higher to lower energy levels. The pattern of the spectra is a characteristic of the specific gas.
- Absorption spectra are formed when certain frequencies of light are absorbed by a material. These photons are absorbed when their energy is exactly the correct amount to raise an electron from one energy level to another.

Physical Quantities		
Quantity	**Unit name**	**Unit symbol**
Energy (E)	joule	J
Work function (W_0)	joule	J
Frequency (f)	hertz	Hz
Wavelength (λ)	metre	m

Table 2: Units used in **optical phenomena and properties of matter**.

5 EXERCISES

5.1 Exercise 1

1. Describe the photoelectric effect.

2. List two reason why the observation of the photoelectric effect was significant.

3. If I shine ultraviolet light with a wavelength of 288 nm onto some aluminium foil, what would the kinetic energy of the emitted electrons be?

4. I shine a light of an unknown wavelength onto some silver foil. The light has only enough energy to eject electrons from the silver foil but not enough to give them kinetic energy.

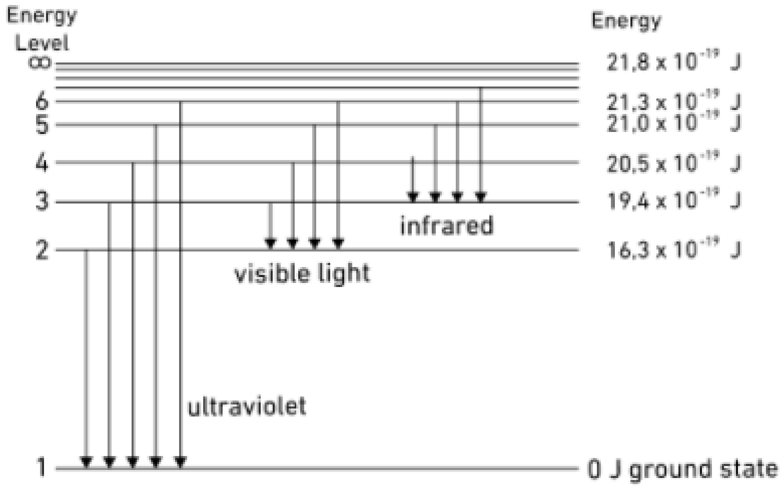
    4.1 If I shine the same light onto some copper foil, would electrons be ejected?

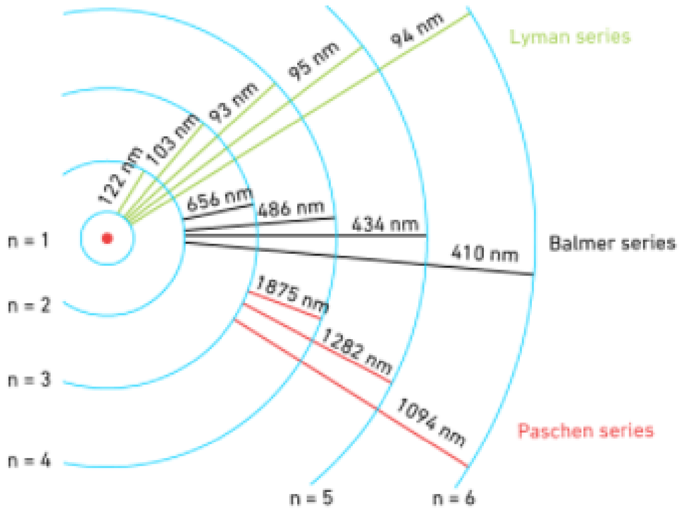
    4.2 If I shine the same light onto some silicon, would electrons be ejected?

    4.3 If I increase the intensity of the light shining on the silver foil, what happens?

    4.4 If I increase the frequency of the light shining on the silver foil, what happens?

5.2 Exercise 2





Use the diagram above to answer the following questions.

1. What colour is the light emitted by hydrogen when an electron makes the transition from energy level 5 down to energy level 2?
2. I have a glass tube filled with hydrogen gas. I shine white light onto the tube. The spectrum I then measure has an absorption line at a wavelength of 474 nm. Between which two energy levels did the transition occur?

6 ANSWERS TO EXERCISES

6.1 Exercise 1

1. Electrons are emitted by a metal when light shines on it.
2. Two reasons why the observation of the photoelectric effect was significant are:
   (1) that it provides evidence for the particle nature of light and
   (2) that it opened up a new branch for technological advancement e.g. photo-cathodes (like in old TVs) and night vision devices.
3. $6,25 \times 10^{-22}$ J

4.1 No

4.2 Yes

4.3 More electrons will be ejected from the silver.

4.4 Electrons will be ejected

6.2 Exercise 2

1. 423 nm and the colour is violet
2. 4 and 2