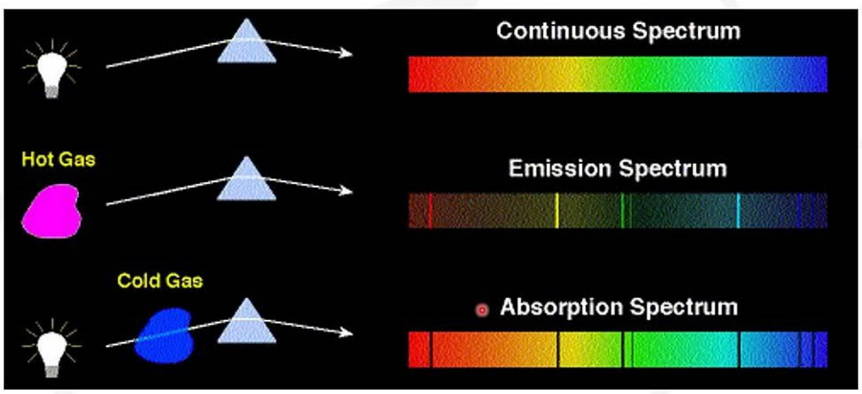

PHYSICS

3.3 Structure of the Atom

ABSTRACT

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Stage 2 Study Notes

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Subtopic 3.3 Structure of the Atom

Students investigate the production and features of line emission spectra from atomic gases to infer the structure of the atom, consisting of excited states with discrete energies.

Students describe and explain the visible continuous spectra emitted by hot objects and atomic absorption spectra.

Students are introduced to the phenomena of a population inversion and stimulated emission to provide a simple explanation of the operation of a laser.

Science Understanding	Possible contexts
A continuous spectrum contains a continuous range of frequencies. Solid, liquid, or dense gaseous objects radiate a continuous spectrum, which may extend into or beyond the visible region. The process is known as incandescence. The frequency distribution, and hence the dominant colour, depends on the temperature of the object. • Describe the changes in the spectrum of a filament globe as the temperature of the filament increases.	Demonstrate changes in the spectrum of an incandescent light globe as voltage increases. Investigate the relationship between temperature and frequency distribution, using a simulation. https://phet.colorado.edu/en/simulation/blackbody-spectrum *Explore examples of the application of incandescence, such as:* • *red hot vs white hot* • *white fireworks* • *filament light bulbs.* *Propose contexts for which the use of each is appropriate.*
Atoms can be raised to excited states by heating or by bombardment with light or particles such as electrons. The heated vapour of a pure element emits light of discrete frequencies, resulting in a line emission spectrum when the light is viewed with a spectrometer. • Describe the general characteristics of the line emission spectra of elements. • Explain how the uniqueness of the spectra of elements can be used to identify the presence of an element. • Explain the production of characteristic X-rays in an X-ray tube.	*Investigate the relationship between temperature and frequency distribution, using a simulation.* https://phet.colorado.edu/en/simulation/blackbody-spectrum *Use flame tests to identify various metal atoms.* *Use spectroscopes to identify gases in a fluorescent light globe.*

Science Understanding	Possible contexts
The presence of discrete frequencies in the spectra of atoms is evidence for the existence of different states in atoms. The states have their own specific energies. The different energies can be represented on an energy-level diagram. When an electron makes a transition from a higher-energy state to a lower-energy state in an atom, the energy of the atom decreases and can be released as a photon. The energy of the emitted photon is given by the difference in the energy levels of the atom. An atom is in its ground state when its electrons have their lowest energy. If an electron is in any of the higher-energy states, the atom is said to be in an excited state. • Explain how the presence of discrete frequencies in line emission spectra provides evidence for the existence of states with discrete energies in atoms. • Solve problems involving emitted photons and energy levels of atoms. • Draw energy-level diagrams to represent the energies of different states in an atom. • Given an energy-level diagram, calculate the frequencies and wavelengths of lines corresponding to specified transitions.	*Explore advantages and disadvantage of using vapour lamps (e.g. neon lights and sodium-vapour street lamps). When is the use of one type more appropriate than the other?* *Explore how the temperature of stars is determined from the spectrum of emitted light. How confident of their accuracy can scientists be?*
The line emission spectrum of atomic hydrogen consists of several series of lines. • Draw, on an energy-level diagram of hydrogen, transitions corresponding to each of the series terminating at the three lowest-energy levels. • Relate the magnitude of the transitions on an energy-level diagram to the region in the electromagnetic spectrum of the emitted photons (ultraviolet, visible, or infrared).	*Observe the emission spectrum of hydrogen using a vapour lamp and spectroscope or simulation.* www.phet.colorado.edu/en/simulation/hydrogen-atom *Discuss the energy-level diagram of hydrogen and relate to the line emission spectrum of hydrogen. Illustrate the transitions corresponding to the first three series of the hydrogen emission spectrum.*
The ionisation energy of hydrogen is the minimum energy required to remove the electron from hydrogen in its ground state. • Using an energy-level diagram, determine the ionisation energy (in either joules or electronvolts) of hydrogen.	*Compare and contrast the concept of ionisation in physics with the formation of metal ions.*
When light with a continuous spectrum is incident on a gas of an element, discrete frequencies of light are absorbed, resulting in a line absorption spectrum. The frequencies of the absorption lines are a subset of those in the line emission spectrum of the same element. • Describe the line absorption spectrum of atomic hydrogen.	*Demonstrate line absorption spectra of various elements using simulation and relate to emission spectra and energy level diagram.* www.phet.colorado.edu/en/simulation/hydrogen-atom *Analyse the solar spectrum and discuss sources of Fraunhofer lines.*

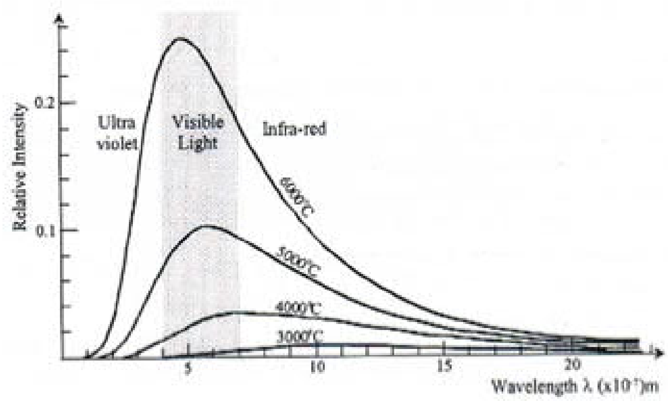
Science Understanding	Possible contexts
• On an energy-level diagram, draw transitions corresponding to the line absorption spectrum of hydrogen. • Explain why there are no absorption lines in the visible region for hydrogen at room temperature. • Account for the presence of absorption lines (Fraunhofer lines) in the Sun's spectrum.	*Explore how line absorption spectra can be used to make discoveries and reliable predictions about the composition and motion of stars.*
When an atom absorbs a photon, it is elevated to an 'excited state', which has a higher energy. Excited states are generally short-lived and the atom returns spontaneously to its ground state, often by emitting a series of lower-energy photons. 'Fluorescence' is the process where an atom absorbs a photon to reach an excited state, but then reverts to the ground state emitting two or more photons with lower energy and longer wavelength. • Draw, on an energy-level diagram of hydrogen, the production of multiple photons via fluorescence. Lasers use the process of stimulated emission to produce electromagnetic radiation. In many lasers stimulated emission occurs from atoms that are in a higher-energy state. When a photon with energy corresponding to a transition from a higher-energy state to a lower-energy state is incident on an atom in the higher state, it can stimulate a transition to the lower state. This results in two identical photons; the original photon and a second photon that results from the transition. Compare the process of stimulated emission with that of ordinary (or spontaneous) emission.	*Investigate innovative applications of fluorescence, such as:* • *biosensors* • *currency security features* • *forensic science* • *mineralogy* • *optical brighteners* • *gene identification* • *defect and leak detection.* *Consider the advantages and disadvantages of their use in different contexts.* *Illustrate the process of stimulated emission on an energy-level diagram or by using a simulation.* www.phet.colorado.edu/en/simulation/lasers *Discuss the properties of laser light and hence the safety precautions that must be used when handling lasers.* *Research the multiple lines of evidence and international communication that contributed to the development of the laser.* *Explore the ways in which lasers can be used to solve problems.*
The photon emitted in stimulated emission is identical (in energy, direction, and phase) to the incident photon. • Explain how stimulated emission can produce coherent light in a laser. A population inversion is produced in a set of atoms whenever there are more atoms in a higher-energy state than in a lower-energy state. For practical systems, the higher-energy state must be metastable if a population inversion is to be produced. • Explain the conditions required for stimulated emission to predominate over absorption when light is incident on a set of atoms. The energy carried by a laser beam is concentrated in a small area and can travel efficiently over large distances, giving laser radiation a far greater potential to cause injury than light from other sources. • Describe the useful properties of laser light (i.e. it is coherent and monochromatic, and may be of high intensity). • Discuss the requirements for the safe handling of lasers.	*Examples include:* • *LADS (laser airborne depth sounder) for aircraft-based hydrographic surveying* • *laser cutting and welding* • *laser surgery* • *optical data storage* • *communication using fibre optics.* *Research the international collaboration and communication of scientists from several countries, including Australia, in the joint project LIGO (Laser Interferometer Gravitational-Wave Observatory) to detect gravitational waves.*

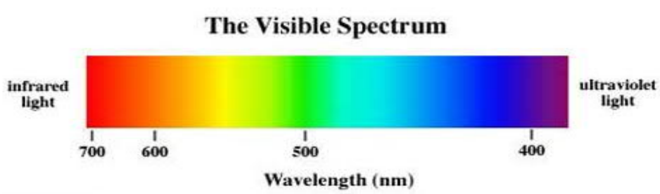
1 Continuous Spectrum.

1.1 Introduction

A continuous spectrum consists of a continuous range of frequencies. All solids, all liquids and dense gaseous objects radiate a continuous spectrum, which may extend into the visible region or beyond in the whole electromagnetic spectrum. The most familiar example is visible light (ROYGBIV). This spectrum consists of all visible frequencies and extends beyond to ultra-violet in one end and infra-red in other end.

1.2 Production.





All solids consist of atoms in constant motion. These atoms consist of charged particles that vibrate. Oscillating charged particles emit electromagnetic waves of the same frequency as the frequency of oscillation of the charged particles. Because of the complex nature of molecular bonding in solids, the particles do not all vibrate with the same frequency. The vibrating particles have a wide and continuous range of frequencies and thus emit electromagnetic radiation with a wide range of frequencies. This is called continuous spectrum.

1.3 Effect of Temperature.

Kinetic theory suggests that temperature is a mixture of the kinetic energy of the particles. If we increase the temperature, the particles vibrate faster at greater frequencies and thus higher intensities (Brightness).

Hence the frequency (range) and intensity of the radiation emitted is only dependent on the temperature of the material on continuous spectrum.

At normal room temperature matter emits electromagnetic radiation in the infra-red region of the spectrum and below. As the temperature increases, the particles vibrate at higher frequencies and eventually emit higher frequencies in the visible spectrum region, and so the matter glows.

The spectrum of the sun and the other stars are essentially continuous and astronomers are able to estimate the temperature of the stars by the intensity of colours in the spectrum of the stars. Cool stars (less than 3000^0C) are rich in red end frequencies and appear reddish. Hotter stars appear whiter because of the bluer frequencies. Very hot stars (more than 30000^0C) are faint because a higher proportion of frequencies are produced in UV region and therefore are not visible.

The distribution of the emitted frequencies and hence the colour of a hot object depends on its temperature.

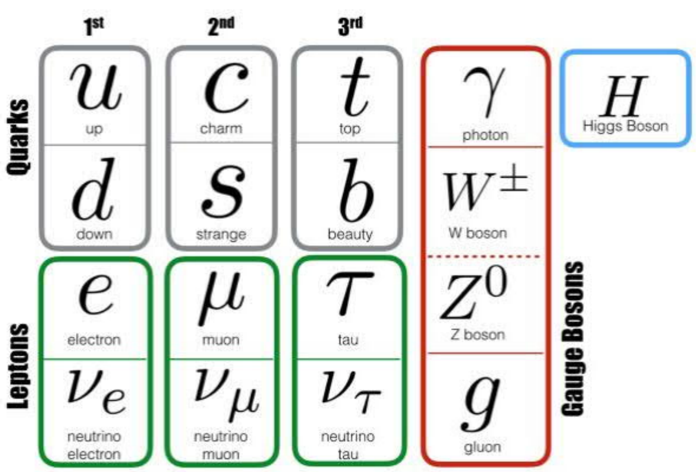
Note

- The colour of visible light depends upon its frequency. But
- The dominant colour of the emission will depends on the frequency of the vibration, which depends on the temperature of the object.

1.4 The Tungsten Filament Globe.

At room temperature light globes emit electromagnetic radiation in the far infra-red region of the spectrum. As the temperature increases the frequency of emission gradually increases and moves into near infra-red region. As the temperature increases further the frequencies move to the red region of visible spectrum and the globe starts to glow 'red hot'. If the temperature is further increased, the frequency is also increased until it is emitting all visible frequencies from red to violet. At this point the globe glows 'white hot'.

Still if the temperature increased furthermore, the filament will become 'faint' because a higher proportion of frequencies are produced in the UV region and are therefore not visible.



PHYSICS

3.4 Standard Model

ABSTRACT

This study notes have been developed and written to meet the scope and syllabus of all the content of the Stage 2 Physics 2020. The goal of this topic is to enable students not just to recognize concepts, but to work with them in ways that will be useful in final exam.

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Stage 2 Study Notes

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Subtopic 3.4 Standard Model

In this subtopic students explore theories that describe the composition of subatomic particles and how interactions between those particles can then be used to describe phenomena such as electrostatic repulsion, beta decay, and positron–electron annihilation.

<table>
<tr><th>Science Understanding</th><th>Possible contexts</th></tr>
<tr><td>
The Standard Model suggests that there are three fundamental types of particles: gauge bosons, leptons, and quarks.

The Standard Model identifies four fundamental forces: electromagnetic, weak nuclear, strong nuclear, and gravitational.

Gauge bosons are particles which mediate the four fundamental forces. They are often called ‘exchange particles’.

<table>
<tr><th>Force</th><th>Gauge Boson</th></tr>
<tr><td>Electromagnetic</td><td>photon</td></tr>
<tr><td>Weak nuclear</td><td>W, Z</td></tr>
<tr><td>Strong nuclear</td><td>gluon</td></tr>
<tr><td>Gravitational</td><td>graviton</td></tr>
</table>
The gauge boson for gravitational forces, the graviton, is still to be discovered.

• Describe the electromagnetic, weak nuclear, and strong nuclear forces in terms of gauge bosons.
Leptons, such as electrons, are particles that are not affected by the strong nuclear force.
Quarks are fractionally charged particles that are affected by all of the fundamental forces.
Quarks combine to form composite particles and are never directly observed or found in isolation.

• Distinguish between the three types of fundamental particles.
</td><td>
This uses the concept of the nucleus developed in Stage 1, Subtopics 6.1: The Nucleus, and 6.2: Radioactive decay.
Use the online interactive from the Particle Data Group at Lawrence Berkeley National Laboratory to develop an understanding of the Standard Model.
http://www.particleadventure.org/
Use the following resource on quarks:
http://neutrinoscience.blogspot.co.uk/2015/07/pentaquark-series-what-are-quarks.html
Discuss the research using the Large Hadron Collider which has found that some particles are formed from combinations of four and five quarks:
http://www.symmetrymagazine.org/article/july-2015/lhc-physicists-discover-five-quark-particle
Discuss the adaptation of the Standard Model to include the Higgs boson, to account for the finite masses of various leptons and quarks.
Feynman diagrams can show how gauge bosons mediate the fundamental forces.

Explore the change in understanding of the Standard Model in the light of new information using, for example, high-energy particle accelerators.
Explore the benefits and limitations of using positron–electron annihilation in PET scanners, including for the production of gamma rays.
Research the economic and social impacts of using the cyclotron at SAHMRI to produce radioisotopes for PET scanning.
</td></tr>
</table>

Science Understanding

There are six types of quark, with different properties, such as mass and charge. Each quark has a charge of either +2/3 or –1/3.

Quark	Symbol	Charge (e)
Up	u	2/3
Down	d	–1/3
Strange	s	–1/3
Charm	c	2/3
Top	t	2/3
Bottom	b	–1/3

All other composite matter particles, such as atoms, are thought to be combinations of quarks and leptons.
Baryons are composite particles that consist of a combination of three quarks.

- Describe how protons, neutrons, and other baryons can be formed from different combinations of quarks.

Each particle is assigned a lepton number and a baryon number.
Lepton numbers can be one of three types:

- electronic lepton number, L_e
- muonic lepton number, L_μ
- tauonic lepton number, L_τ.

The lepton number, regardless of type, for a lepton is 1. All other particles have a lepton number of 0.
The baryon number of a quark is 1/3. All other particles have a baryon number of 0.
For every matter particle there exists an antimatter particle equivalent.
Antiquarks have a baryon number of –1/3 and antileptons have a lepton number of –1. Antiquarks have the opposite charge to their quark equivalent. Quarks and antiquarks can form particles called mesons.

The laws of the conservation of baryon number, charge, and lepton number determine the types of reactions that can occur between particles.

- Use the conservation laws to determine the baryon number, lepton number, and charge of particles in reactions.
- Given a reaction between particles, demonstrate that baryon number, lepton number, and charge are conserved.

When a particle and its antiparticle collide, they annihilate, releasing energy according to the mass–energy equivalence formula: $E = \Delta mc^2$.

Possible contexts

Explore how beta minus decay involves the conversion of a neutron to a proton accompanied by the production of an electron and an antineutrino.
Explore how beta plus decay involves the conversion of a proton to a neutron, accompanied by the production of an electron and an antineutrino.
Explore how beta decay can be explained in terms of the conversion of quarks.

1 Introduction

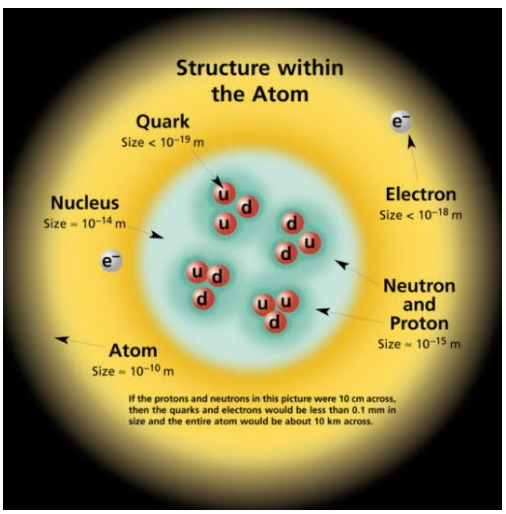
All matter is made up of atoms. Up to this point of this course, the atom has been described as having a tiny dense nucleus consisting of protons and neutrons and electrons that orbit the nucleus.

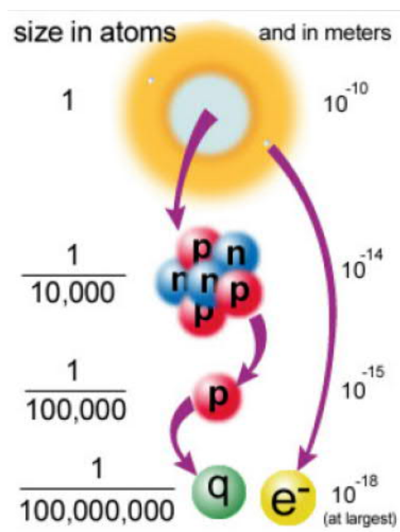
Particle physics is a branch of physics that studies the elementary constituents of matter and radiation, and the interactions between them. It is also called "high energy physics", because many elementary particles do not occur under normal circumstances in nature, but can be created and detected during energetic collisions of other particles, as is done in particle accelerators

The Standard Model was developed in response to the discovery of these new particles. The Standard Model describes the particles that form the fundamental building blocks of matter and the forces that govern their behaviour.

A Sub-atomic particles are particles that are smaller than the atom. An elementary particle or fundamental particle is a particle not known to have substructure; that is, it is not known to be made up of smaller particles. If an elementary particle truly has no substructure, then it is one of the basic particles of the universe from which all larger particles are made.

2 Hierarchy of Particles





- Stuff you see around you is made up of molecules.
- Molecules are made up of Atoms.
- Atoms are made up of Nuclei and Electrons.
- Nuclei are made up of protons and neutrons (collectively nucleons).
- Nucleons are made from elementary particles like Quarks.
- Quarks and Electrons are (as far as we know) elementary particles.

The Standard Model suggests that there are three fundamental types of particles:

1. Bosons (Exchange particles)

2. Leptons (six types plus their antiparticles)

3. Quarks (six types plus their antiparticles)

3 The Four Forces of Nature

Particle interactions are expressed in terms of four fundamental forces. In order of decreasing strength, these forces are the strong nuclear force, the electromagnetic force, the weak nuclear force, and the gravitational force.

3.1 The Strong Nuclear Force.

The strong nuclear force is responsible for holding the nucleus together. It is the strongest of all the forces but is a very short-range force. That is, its effects occur within a distance of about 10^{-15} m, the diameter of the nucleus. At distances greater than this, there is no evidence whatsoever for its very existence. Not all particles participate in the strong nuclear force; for instance, electrons and neutrinos are not affected by it. The strong nuclear force acts only on the hadrons (combinations of quarks)

The strong nuclear force holds quarks together to form hadrons; its carrier particles are whimsically called gluons because they so successfully "glue" the quarks together. The binding of protons and neutrons to form nuclei is a residual strong interaction effect due to their strongly-interacting quark and gluon constituents. Leptons (electrons) have no strong interactions.

3.2 The Electromagnetic Force.

They are responsible for binding the electrons to the nucleus to form electrically-neutral atoms. Atoms combine to form molecules or crystals because of electromagnetic effects due to their charged substructure. Most everyday forces, such as the support of the floor or friction, are due to the electromagnetic forces in matter that resist displacement of atoms or electrons from their equilibrium positions in the material.

In particle processes the forces are described as due to the exchange of particles; for each type of force there is an associated carrier particle. The carrier particle of the electromagnetic force is the photon; gamma ray is the name given a photon from a nuclear transition.

More energetic photons are exchanged when the electrons are closer to one another. This explains why the electromagnetic force a stronger when the electrons are closer. Conversely, less energetic photons are exchanged when the electrons are further apart, and the electromagnetic force is weaker.

It is only 1/100 the strength of the strong nuclear force. The electromagnetic force holds atoms, molecules, solids, and liquids together. Like gravity, it is a long-range force varying as $1/r^2$

3.3 The Weak Nuclear Force.

They are responsible for the fact that all the more massive quarks (p,n) and leptons (e) decay to produce lighter quarks and leptons. That is why stable matter around us contains only electrons and the lightest two quark types (up and down). The carrier particles of weak interactions are the W and