Section 4.2.5 – Production of Light

The Production of Light: Lasers

The term LASER is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation

Figure 1 – laser pointers

Ordinary photon emission is called **spontaneous emission**, but the atoms in a laser undergo **stimulated emission**.

Atoms in a gas are in an excited state (ie. electrons in a high energy level) due to an external energy source. When such atoms encounter a photon that matches their **excitation energy**, they **transition** to the ground state and emit a **photon that is identical to the first photon**, in energy, phase and direction.

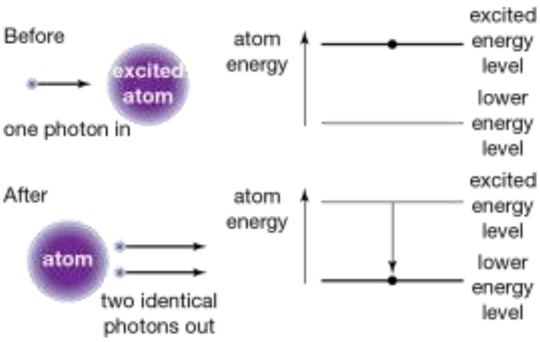

***Figure 2** – energy transitions*

If this photon passes another electron in an excited state it can stimulate the transition of that electron to the ground state too and emit a second identical photon. These photons are **coherent**. As seen in Figure 2.

These two photons could stimulate the emission of two more photons, resulting in four identical photons, then, eight, sixteen and so on — like a nuclear chain reaction.

To increase the chance of a photon stimulating another photon emission, the laser cavity that contains the gas has **mirrors on both ends**, reflecting photons back and forth through the lasing material many times. The mirror at one end of the cavity is only **partially reflecting**. The photons passing through it form the laser beam.

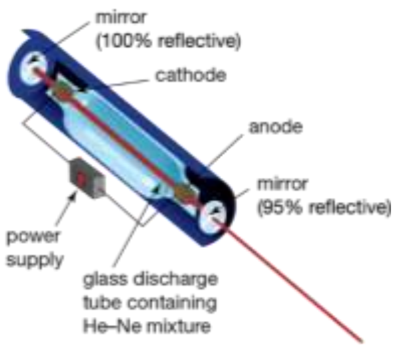

***Figure 3** – laser construction*

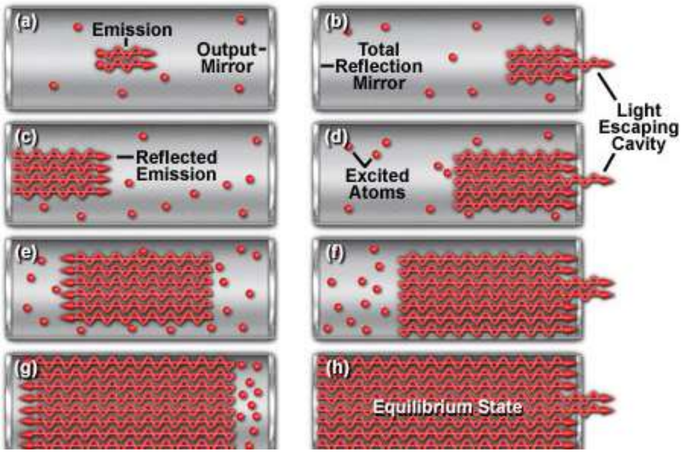

***Figure 4** – stimulated emission in a laser cavity*

The distance between the mirrors is a whole number of half-wavelengths, so a standing wave is set up between them.

The colour of laser light is determined by the energy level structure of the atoms, or, for some lasers, the ions, which emit its characteristic photons.

The Production of Light: Synchrotrons

A synchrotron is a large machine that accelerates electrons to almost the speed of light. As the electrons are deflected through magnetic fields they create extremely bright light, called synchrotron radiation.

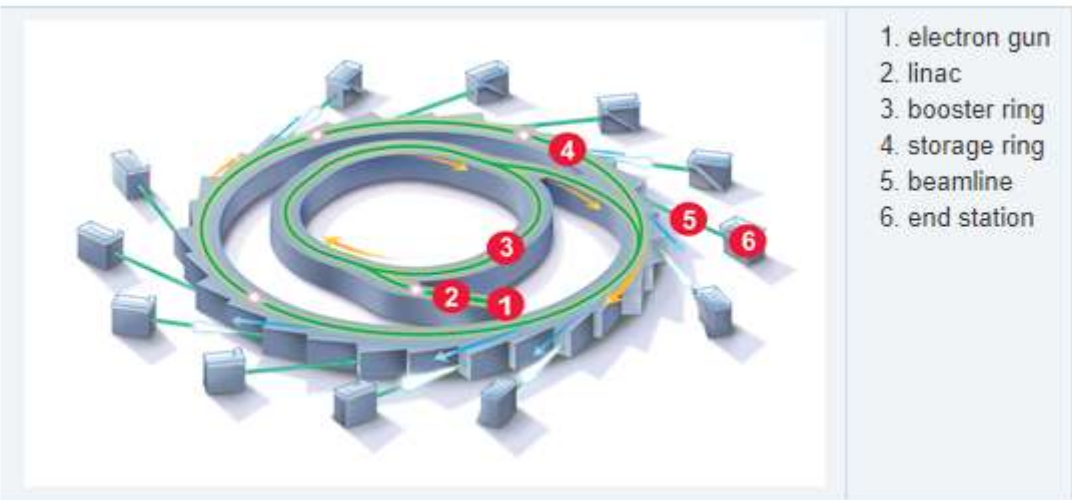

Figure 5 *– Components of the Australian Synchrotron*

You would recall that a moving charged particle generates an electromagnetic field. So too, when an electron is forced to change direction, that is accelerate, by a strong magnetic field, it will also generate a broad range short pulse of electromagnetic radiation.

The generated synchrotron radiation (light) is intense, polarised, and across a wide spectrum (from microwaves to X-rays).

The light is channelled down beamlines to experimental workstations where it is used for research.

Properties of synchrotron light

Synchrotron light has a number of unique properties. These include:

- High brightness: synchrotron light is extremely intense (hundreds of thousands of times more intense than that from conventional x-ray tubes) and highly collimated.

- Wide energy spectrum: synchrotron light is emitted with energies ranging from infrared light to hard x-rays.

- Tunable: it is possible to obtain an intense beam of any selected wavelength.

- Highly polarised: the synchrotron emits highly polarised radiation, which can be linear, circular or elliptical.

- Emitted in very short pulses: pulses emitted are typically less than a nano-second (a billionth of a second), enabling time-resolved studies.

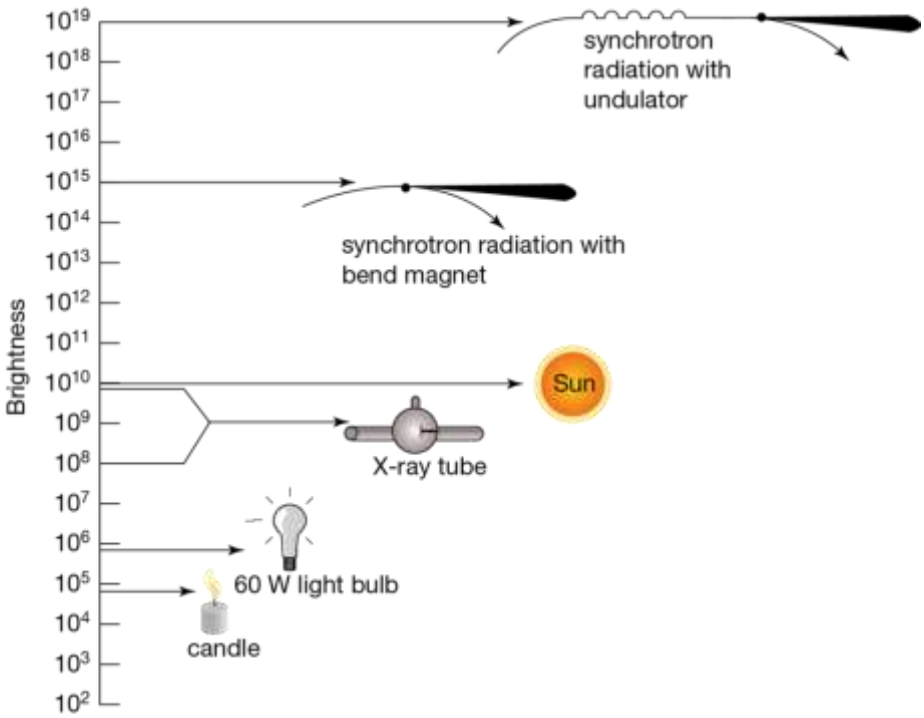

Figure 6 *– Relative brightness of the synchrotron*

As can be seen in Figure 6 above, the Australian Synchrotron (which includes undulators), is a billion time brighter than our sun. A most impressive fact!

The Production of Light: LEDs

***Figure 7** – A range of coloured LEDs*

A **light-emitting diode (LED)** is a small **semiconductor diode** that emits light from its **p–n junction** when it is forward biased and a current passes through it.

Semiconductors are materials whose properties are midway between those of a good conductor and a good insulator. This is represented in Figure 7.

The **valence band** is the **highest filled band** of energy for electrons in an atom.
The **conduction band** is the **lowest unfilled band** of energy for electrons in an atom. Electrons in this band can easily move from one atom to the next, hence conducting electricity.

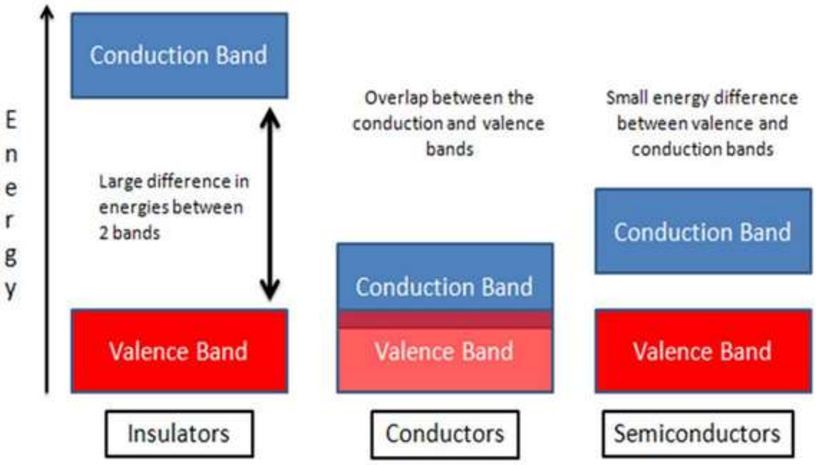

***Figure 8** – Classifications of materials based upon energy differences*

An **n-type semiconductors** have **spare electrons** in the **conduction band**.
A **p-type semiconductors** have **spare 'holes'** (an absence of electrons) in the **valence band.**

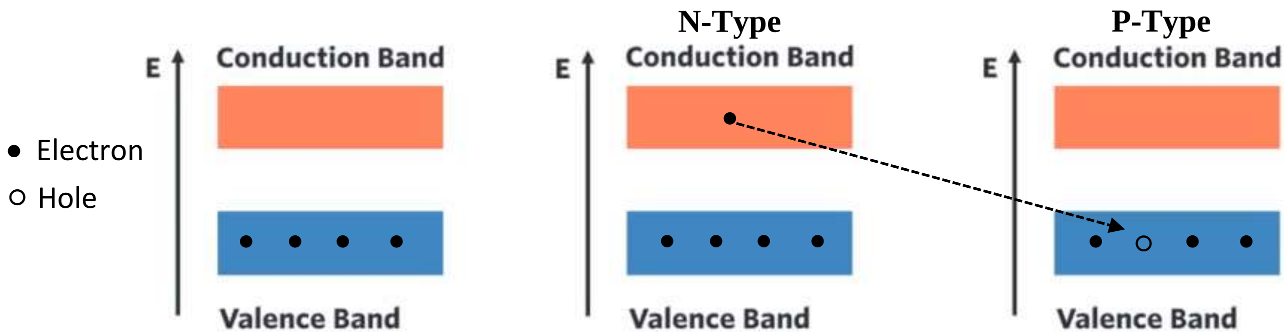

***Figure 9** – N-Type and P-Type semiconductors*

LEDs use both n-type and p-type semiconductors. As current passes through, electrons move **from the conduction band** of the n-type into the **holes in the valence band** of the p-type, as shown by the dotted line in Figure 9.

This emits a photon with a **particular wavelength** corresponding to the **change in energy of the electron** ($\Delta E = hf$).

The Production of Light: Incandescent Light

Incandescent light sources emit light because of their **temperature.** They are thermal sources. Light bulbs with filaments are an example of an incandescent light source.

Incandescent light bulbs (Figure 10) emit light by using an **electric current** to heat a **tungsten filament**. Tungsten is used because it is a metal and has a **high melting point**. The **range of colours** of light emitted depends on the **temperature** of the filament.

Figure 10 *– Incandescent light bulb*

Light is emitted on a **continuous spectrum of wavelengths** due to **thermal vibrations** of atoms.

The **intensity of each wavelength** is dependent on the **temperature** of the material emitting the light.

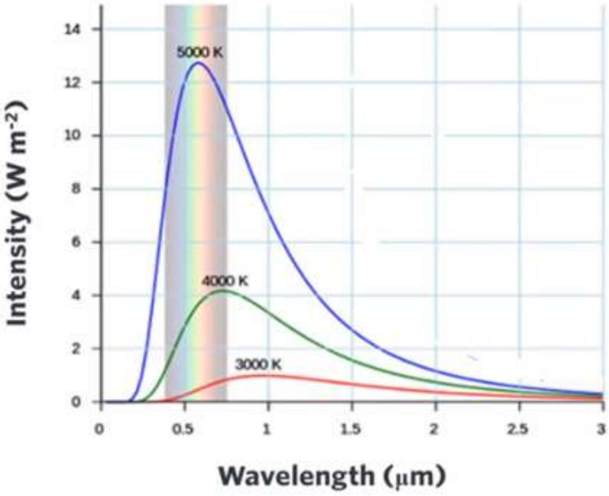

Figure 11 *- Intensity V Wavelength @ different temperatures*

Figure 11 displays that fact that the higher the temperature of a metal, the smaller the wavelength of light produced.

Comparison of light sources

Light Source	Cause of light production	Features of the light
Laser	Electron transitions in atoms in a gas due to stimulated emission	Coherent, polarised
Synchrotron	Acceleration (deflection) of charged particles (electrons) due to magnetic fields	Wide range of wavelengths, polarised, very intense (can be coherent)
LED	Electron transition in semiconducting material from conduction band to valence band	Can be monochromatic (single wavelength)
Incandescent	Acceleration of charged particles due to thermal vibrations	Continuous spectrum

Exam Style Questions

Question 1
Which of the following best describe the way light is produced in a laser?

A. Light is emitted as charged particles accelerate due to the thermal energy
B. Light is emitted as electrons change energy levels as a result of a stimulated emission
C. Light is emitted as electrons change energy levels from a conduction band to a valence band
D. Electrons are accelerated and deflected using strong magnetic fields. Light is emitted as a result of this acceleration/deflection of charged particles.

*Lasers are to do with electrons **changing energy levels**. "**Stimulated emissions**" is another key term for lasers and indeed part of the acronym for LASER.*

B

Question 2
Which of the following best describe the way light is produced in a synchrotron?

A. Light is emitted as charged particles accelerate due to the thermal energy
B. Light is emitted as electrons change energy levels as a result of a stimulated emission
C. Light is emitted as electrons change energy levels from a conduction band to a valence band
D. Electrons are accelerated and deflected using strong magnetic fields. Light is emitted as a result of this acceleration/deflection of charged particles.

*A synchrotron requires the **acceleration and deflection** of electrons in order to produce synchrotron radiation.*

D

Question 3
What is the best description of how light is produced in an LED?

A. Thermal motion of electrons in the valence band
B. Transition of electrons from the conduction band to the ground state
C. Transition of electrons from the conduction band to the valence band
D. Transition of electrons from the valence band to the conduction band

*Correct answer requires a transition from **conduction band** to **valence band**.*

C

Question 4
Which of the following best describe the way incandescent light is produced?

A. Light is emitted as charged particles accelerate due to the thermal energy
B. Light is emitted as electrons change energy levels as a result of a stimulated emission
C. Light is emitted as electrons change energy levels from a conduction band to a valence band
D. Electrons are accelerated and deflected using strong magnetic fields. Light is emitted as a result of this acceleration/deflection of charged particles.

*Incandescent light is dependent upon **thermal vibrations** or **thermal energy**.*

A

Question 5
Which of the following lists includes only forms of light which are caused by the transition of electrons between energy levels?

A. Laser, LEDs
B. Laser, synchrotron
C. Laser, synchrotron, LEDs
D. Synchrotron, incandescent

*Lasers and LEDs require a **transition between energy levels**. Whereas, synchrotron light is due to the acceleration of electrons and incandescent light requires thermal vibration.*

A

Question 6
Which one of the following statements best describes light produced from a range of sources?

A. Light from an incandescent lamp is generally coherent and contains a wide spectrum of wavelengths.
B. Light from a single-colour light-emitting diode (LED) is coherent and contains a very wide spectrum of wavelengths.
C. Synchrotron light is always incoherent and contains a wide spectrum of wavelengths.
D. Light from a laser is coherent and has a very narrow range of wavelengths.

Incandescent lights <u>do not</u> produce <u>coherent light</u>.
LEDs produce light that has a <u>specific wavelength</u>, not a wide spectrum of wavelengths
Synchrotron light <u>can</u> be coherent

D