Lab 2

KVL, KCL, & the Incandescent Light

Introduction

In this lab you will explore some basic circuit analysis concepts.

- You will use Kirchhoff's Voltage Law (KVL) and Kirchhoff's Current Law (KCL) to help solve circuit values.
- You will use voltage division to help find the voltage divided amongst series resistors.
- You will use an incandescent light, and investigate how its electrical resistance changes with temperature.

Before we can do these experiments, we need to learn about:

- How an incandescent light works.
- How resistance changes with temperature.
- How to use KVL and KCL to analyze circuits.

Incandescent Lights

The Incandescent Light

Picture from Wikipedia

The development of incandescent lamps was very significant.

- They are easier to use than candles and oil lamps, and don't smell.
- They made it inexpensive for people to work at night, improving industrial productivity.

Incandescent lights also do not start fires as easily as candles or oil lamps.

Some people still use candles on their christmas tree.

Picture from Wikipedia

Incandescent Lamp Operation

Incandescent lamps have a tungsten wire filament inside them.

- Electric current flowing through this wire heats it to around 3000 K, which is about 2700 °C. (tungsten melts at 3695 K).
- Incandescence is the emission of visible light at high temperatures.

To improve efficiency, the filament is usually a fine coil of wire.

- In a typical 60 W bulb, this filament might be 1 m long if uncoiled.

Not Just Edison

There were many many people who contributed to the development of the incandescent lamp. Some were:

- In 1802, Sir Humphry Davy created the first incandescent light by passing electric current through a thin strip of platinum.
- In 1840, Warren de la Rue placed a platinum filament in a vacuum tube. This improved its longevity.
- In 1879, Thomas Edison developed a light bulb using a carbonized filament, and later demonstrated that it could last over 1200 hours.
- In 1910, William Coolidge invented an improved method of making tungsten filaments, making the cost of incandescent bulbs practical.

More than 100 years

By the late 1800's, inexpensive and reliable incandescent lights quickly replaced earlier forms of lighting.

Halogen Incandescent Lamps

What is the difference between a normal incandescent lamp and a halogen lamp?

vs.

In 1959, GE sold the first halogen lamps, which used iodine gas.

Halogen lights are typically higher power, brighter and whiter in colour.

But why?

Halogen Incandescent Lamps

Halogen incandescent lamps contain halogen gas, such as iodine (I) or bromine (Br).

- As an incandescent lamp operates, the tungsten filament evaporates and slowly deposits on the inside of the glass (the visible darkening with age).
- In a halogen lamp, the halogen gas combines with the deposited tungsten (W) on the glass, forming a halide gas. For example:

$$Br\ (g) + W\ (s) \longrightarrow WBr_5\ (g)$$

- This gas circulates in the lamp, and when it contacts the hot filament, it dissociates and redeposits the tungsten back on the filament. This increases lifetime and enables operation at higher temperatures (more white colour).

Surface contamination, such oils from your skin, can create hot spots on the quartz bulb, causing it to rupture or explode.

- Quartz lamps should be handled with a clean towel (cloth or paper) or wear gloves. If the quartz is contaminated, clean it with alcohol.

Why do incandescent lamps radiate light?

&

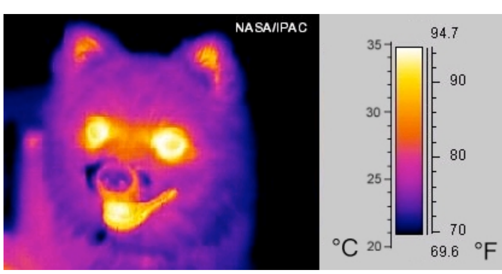
How did this help lead to Quantum Mechanics?

Thermal Emission

All objects above absolute zero temperature (-273.15 °C) radiate energy. The amount of energy, and at what wavelength, depends on its temperature.

- At temperatures near room temperature, the energy radiated is mostly at infra-red wavelengths.

IR image of a dog.



Pictures from Wikipedia

IR image of people.

Thermal Emission - Visible Colours

At higher temperatures, thermal emission occurs at visible light wavelengths.

- As an object’s temperature rises, the incandescent colour transitions though red, orange, yellow, white, then blue.
- Since a light bulb is around 3000 K, the light from it appears yellow-orange in colour.

The temperature of this flowing lava is around 2000 K.

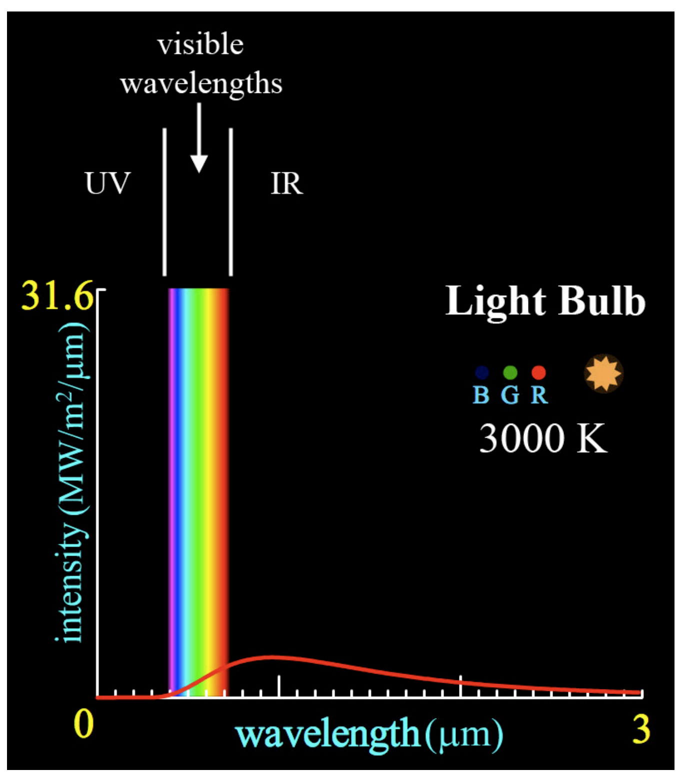
Picture from Wikipedia

Incandescent Lamp Spectrum

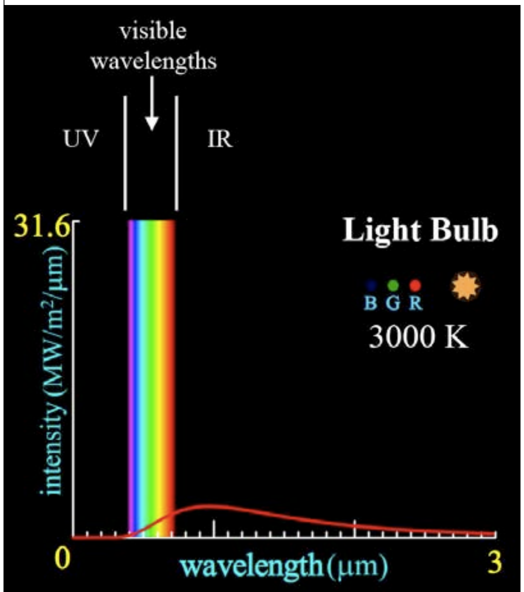
The light from an incandescent lamp is actually not a single colour.

It is a continuous spectrum of energy at all wavelengths.

- The amount of energy at each wavelength depends on the filament temperature.



Incandescent Lamp Efficiency



Is the incandescent lamp an efficient light source?

- The efficiency of a light source depends on whether the energy radiated by the source is at wavelengths that the human eye can see.

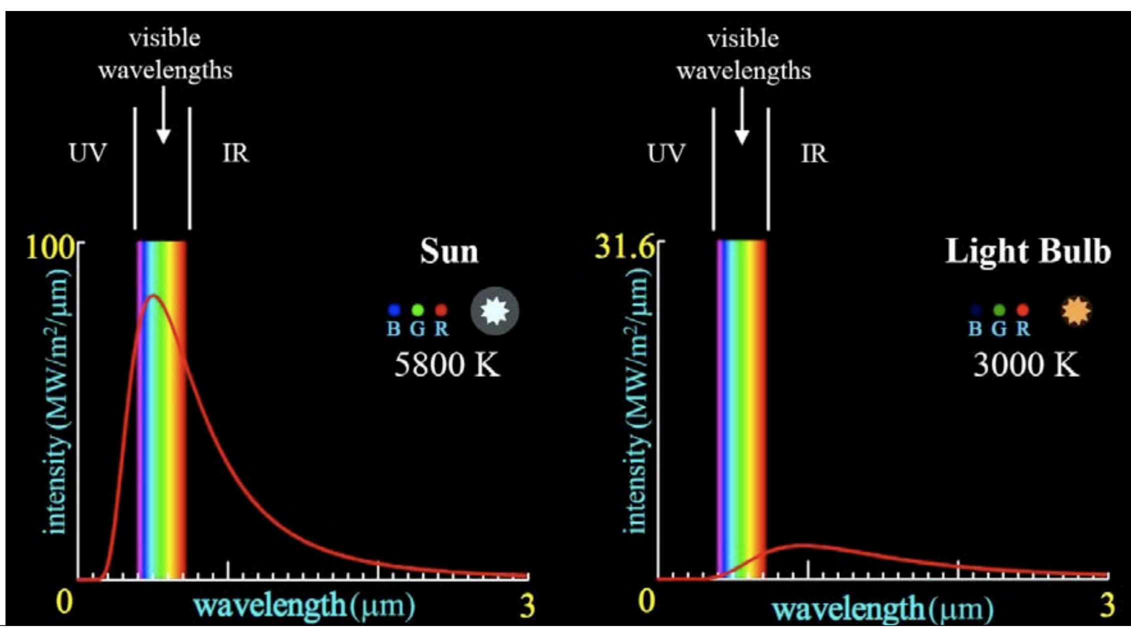
Consider the incandescent lamp. Most of the "light" radiated is at infra-red (IR) wavelengths.

- Therefore, they are inefficient at producing visible light.

Note: In winter we need the heat. And so incandescent lamps are not "inefficient" if the heat is needed.

Comparison With Sun Light

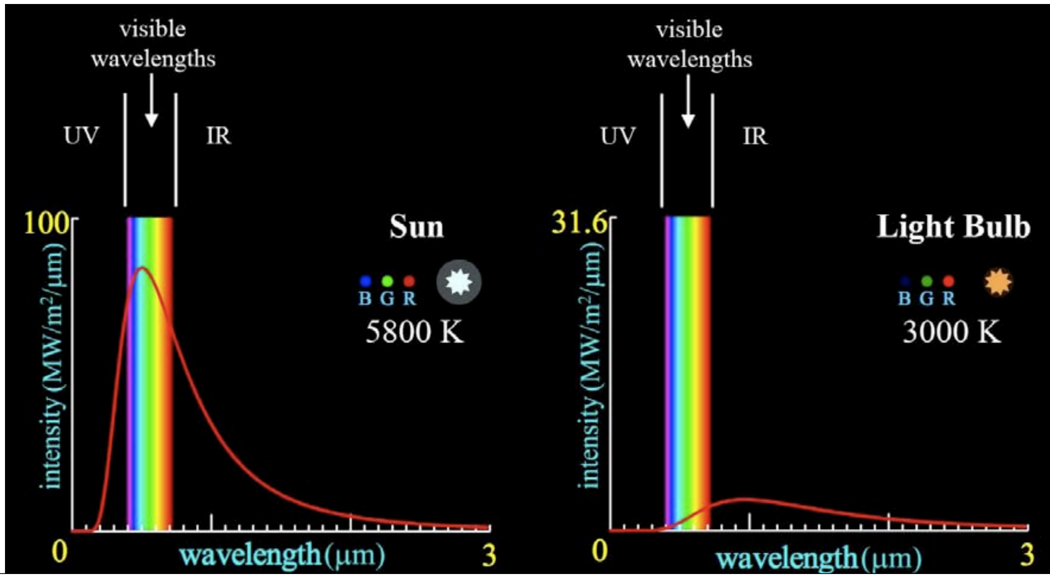
The surface of the sun is much hotter than an incandescent lamp, around 5800 K, and so the sun emits more light in the blue end of the visible spectrum, making the sun appear more white in colour.



Thermal Emission vs. Temperature

This comparison shows us that as an object's temperature increases:

- The intensity of emitted energy is higher.
- The spectrum of energy emission shifts to shorter wavelengths.

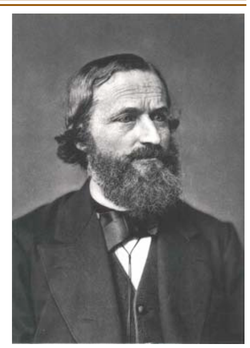


From Light Bulbs To Quantum Mechanics

The German physicist Gustav Robert Kirchhoff (1824 - 1887) stated:

- A hot solid object produces light with a continuous spectrum.

But it took decades of study before people understood how the incandescent spectral intensity varied with wavelength.



In 1900, the German physicist Max Planck (1858 - 1947) finally described the thermal emission spectrum.

- Planck's theory requires energy quantization.
- Planck is one of the founders of quantum physics, and one of the most important physicists of the 20th century.

Interestingly, Planck was commissioned in 1894 by electric companies to improve the efficiency of light bulbs.

Picture from Wikipedia

Resistance Change With Temperature

Resistance Change With Temperature

In today's lab you will investigate how the resistance of the wire filament in an incandescent lamp changes with temperature.

- When the light is off, the filament is at room temperature.
- When it is on, the filament is about 2700 °C.

In general, the resistance of metals:

- Decreases as temperature decreases, and increases as temperature increases.

In general, the resistance of semiconductors and insulators:

- Increases as temperature decreases, and decreases as temperature increases.

Typically the change is small, only a fraction of a % per °C change.

- This phenomena is used in many temperature sensors and thermal controls.

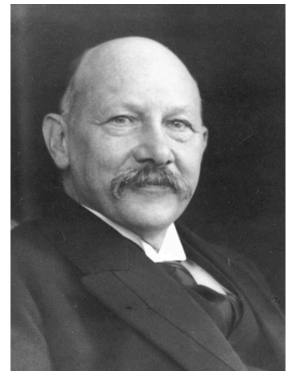
Superconductivity

Some materials become superconductors at low temperatures.

- Superconductive materials have zero electrical resistance.

Superconductivity was first demonstrated in 1911 by the Dutch physicist Heike Kamerlingh Onnes (1853 - 1926).

- He showed that mercury is superconducting at -269 °C.



The superconducting cables on the right side of this picture can carry as much electric current as the copper cables on the left.

Note: The required cooling system around the superconducting cables is not shown.

KVL, KCL & Voltage Division

Kirchhoff’s Circuit Laws

Gustav Kirchhoff also gave us the two laws that form the foundation of circuit analysis.

- Kirchhoff’s current law (KCL)
- Kirchhoff’s voltage law (KVL)

We will use these laws throughout this course to determine the current and voltages at various points in electric circuits.

Kirchhoff formulated these laws in 1845, while still a student.

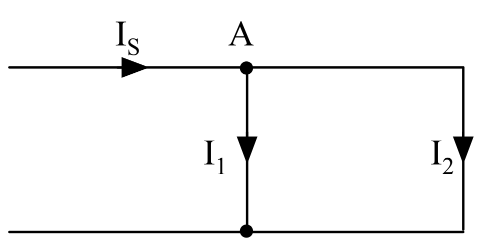
Kirchhoff’s Current Law

KCL states that the sum of the currents flowing into a node in a circuit, is equal to the sum of the currents leaving that node.

- This follows the principle of conservation of charge.

For example, in the below circuit KCL tells us that at node A:

$$I_S = I_1 + I_2$$



Kirchhoff's Voltage Law

KVL states that the sum of the electrical potential differences around any closed circuit loop equals zero.

- This follows the principle of conservation of energy.

For example, in the below circuit KVL tells us:

That in Loop 1:

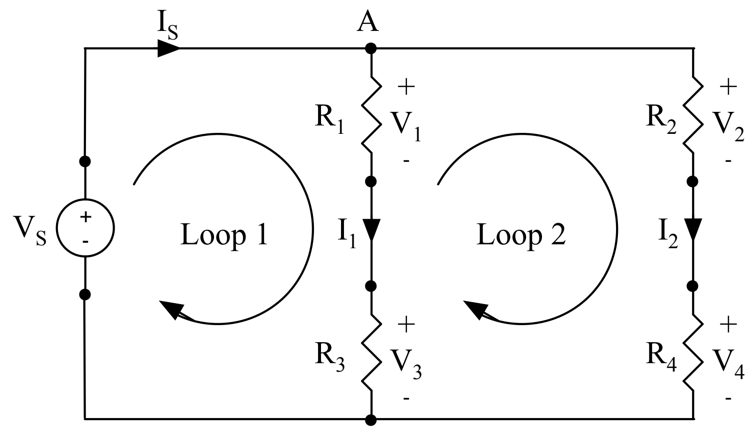
$0 = V_S + (-V_1) + (-V_3)$

or $V_S = V_1 + V_3$

That in Loop 2:

$0 = V_1 + V_3 + (-V_2) + (-V_4)$

or $V_1 + V_3 = V_2 + V_4$



Voltage Division

When two (or more) resistors are connected in series with a voltage source, the source voltage is divided between the resistors.

Consider this circuit. Ohm's law shows:

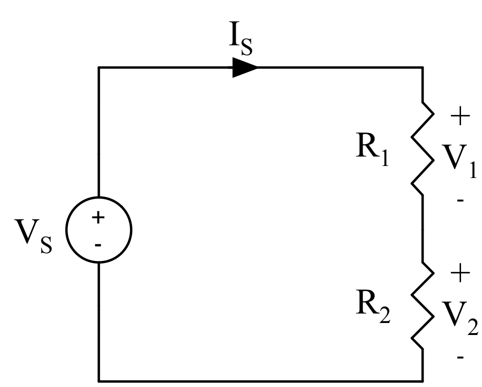
$$I_S = \frac{V_S}{R_1 + R_2} \quad \text{and} \quad V_1 = I_S \times R_1$$

Putting I_S in the equation for V_1 we obtain:

$$V_1 = \frac{V_S}{R_1 + R_2} \times R_1$$

Re-arranging this equation we obtain:

$$V_1 = V_S \times \frac{R_1}{R_1 + R_2}$$



Similarly we can show that:

$$V_2 = V_S \times \frac{R_2}{R_1 + R_2}$$

Important Things To Remember

Important Points

In a halogen incandescent lamp, the halogen gas is used to redeposit evaporated tungsten back onto the filament.

As the temperature of an incandescent object increases, the intensity of emitted energy is higher, and the spectrum of energy emission shifts to shorter wavelengths (from red to blue in the visible wavelengths).

KCL states that the sum of the currents flowing into a node in a circuit, is equal to the sum of the currents leaving that node.

KVL states that the sum of the electrical potential differences around any closed circuit loop equals zero.