



How Can Thermal Effects Be Explained?

Lesson 6, Part 1: Climate Science



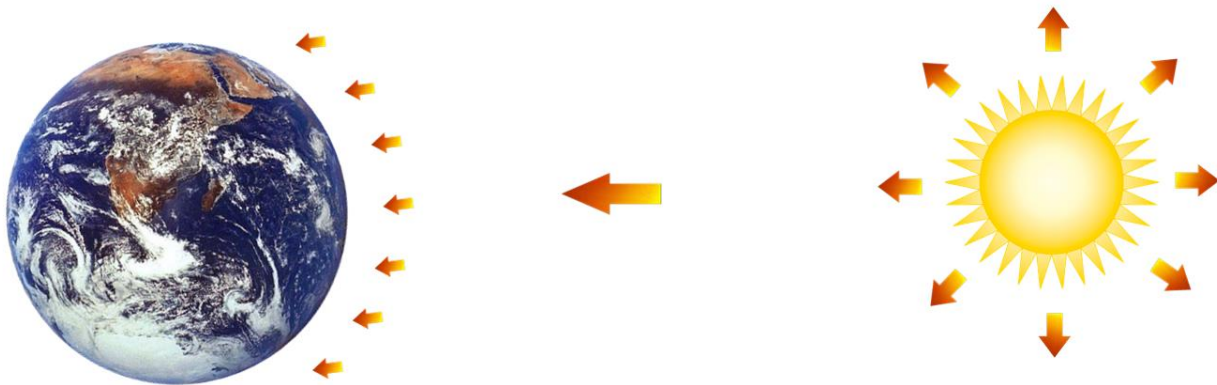
Climate Change...Why the cause for concern?

Climate change is the major, overriding environmental issue of our time, and the single greatest challenge facing environmental regulators. It is a growing crisis with economic, health and safety, food production, security, and other dimensions.

United Nations Environmental Program
<http://www.unep.org/climatechange/>

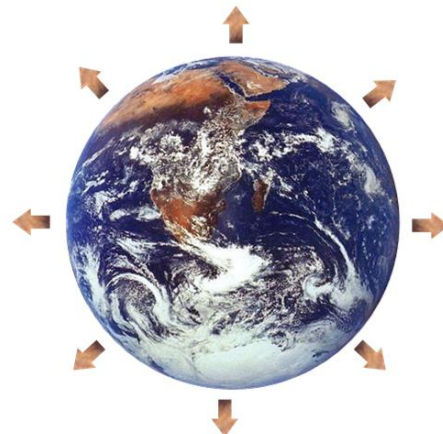
The Earth is solar powered!

Electromagnetic radiation from the Sun reaches the Earth and it.



Electromagnetic radiation is re-r..... from the heated-up Earth.

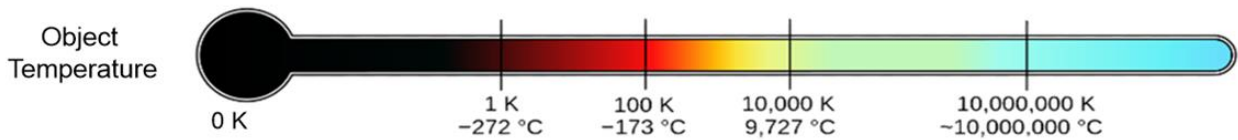
Earth will maintain thermal
(constant average temperature) as long as
energy in (from the sun)
energy out (from the earth).



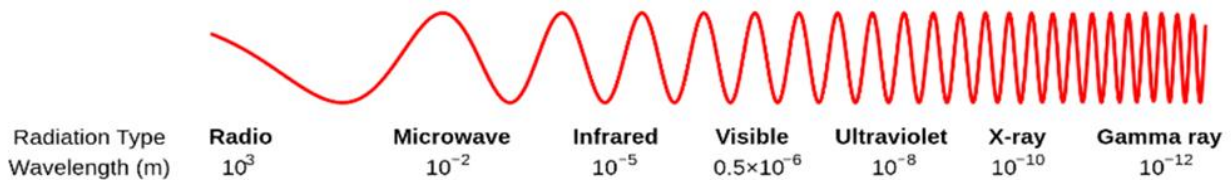
Linear and Logarithmic Scales

Physical values often take on a vast of values.

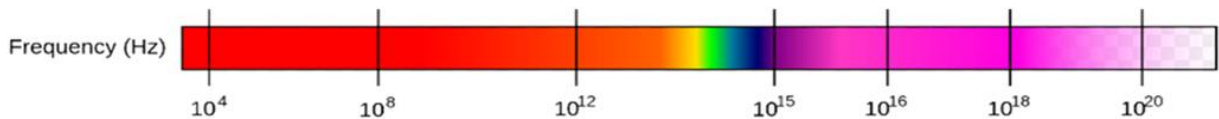
Temperatures can range from absolute zero (0 K) to hundreds of of degrees.



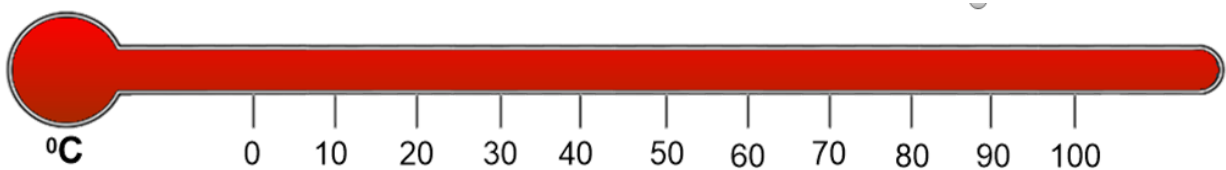
Wavelengths of electromagnetic radiation vary from a tiny 10^{-12} metre for gamma rays to 1000 (10^3) metres for waves.



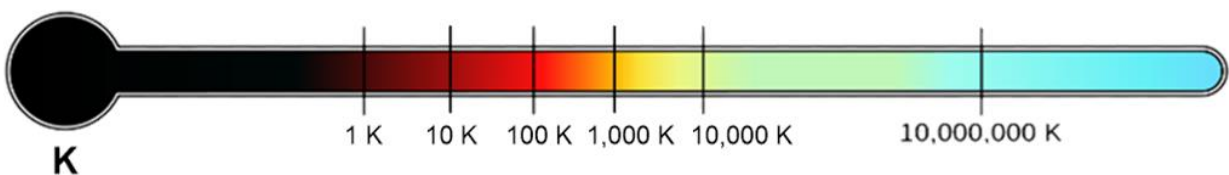
Corresponding **frequencies** of electromagnetic radiation vary from a 10,000 (10^4) Hz for radio waves to 10^{20} Hz for rays.



A **Linear scale** has even scale divisions.



To represent a vast range of values on graphs or diagrams, a **logarithmic scale** is often used.

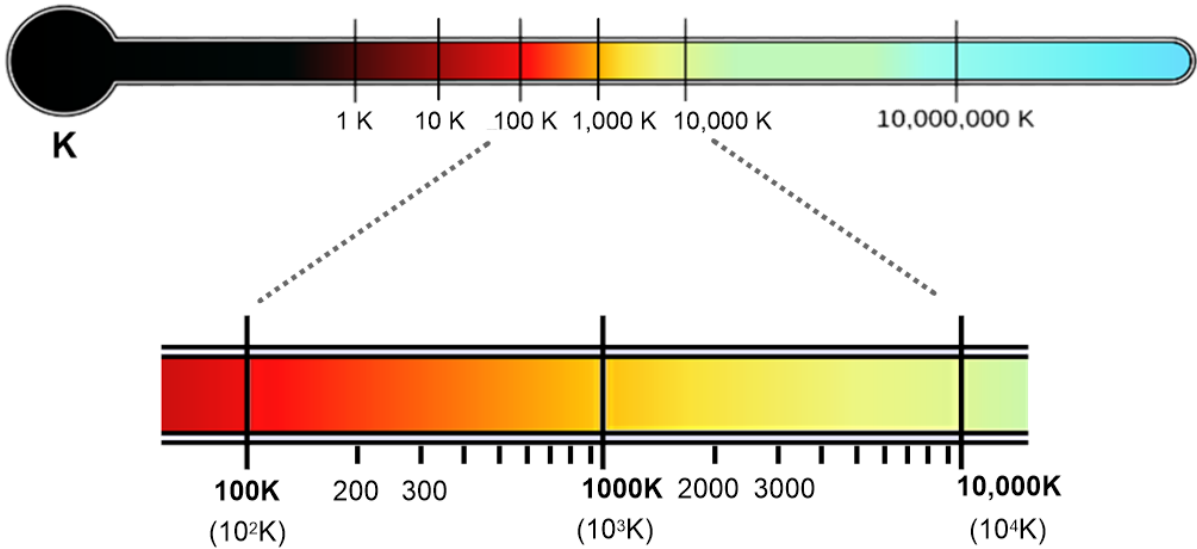


On a logarithmic scale, values go up by a **factor of** for each scale division.

Linear and Logarithmic Scales (Continued)

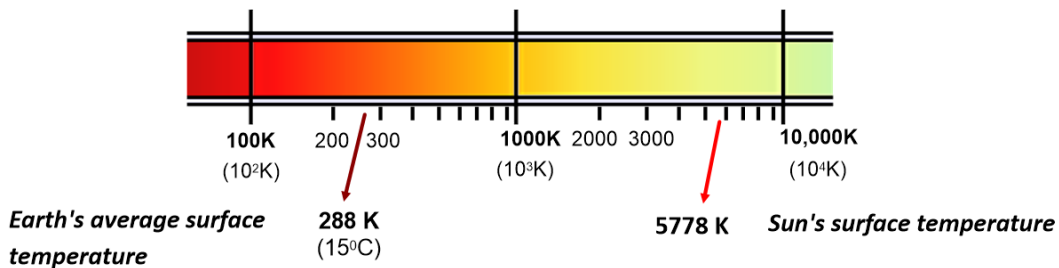
How to interpret logarithmic scales.

Each mark represents a ten-fold increase in the value of the temperature.

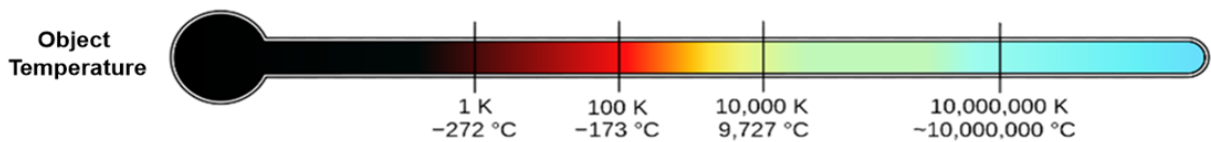


The marks within each 'decade' get closer and closer together and each represent the same change in the temperature.

Surface temperatures for the Earth and the Sun are shown on this logarithmic scale below.



On some **graphs** the horizontal axis represents **increasing f**.....

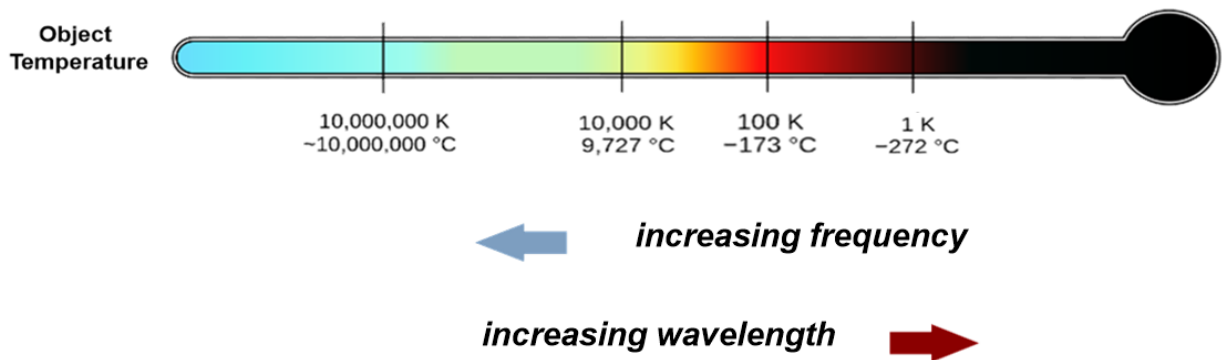


$$c = f\lambda$$

➔ **increasing frequency**
➔ **increasing wavelength**

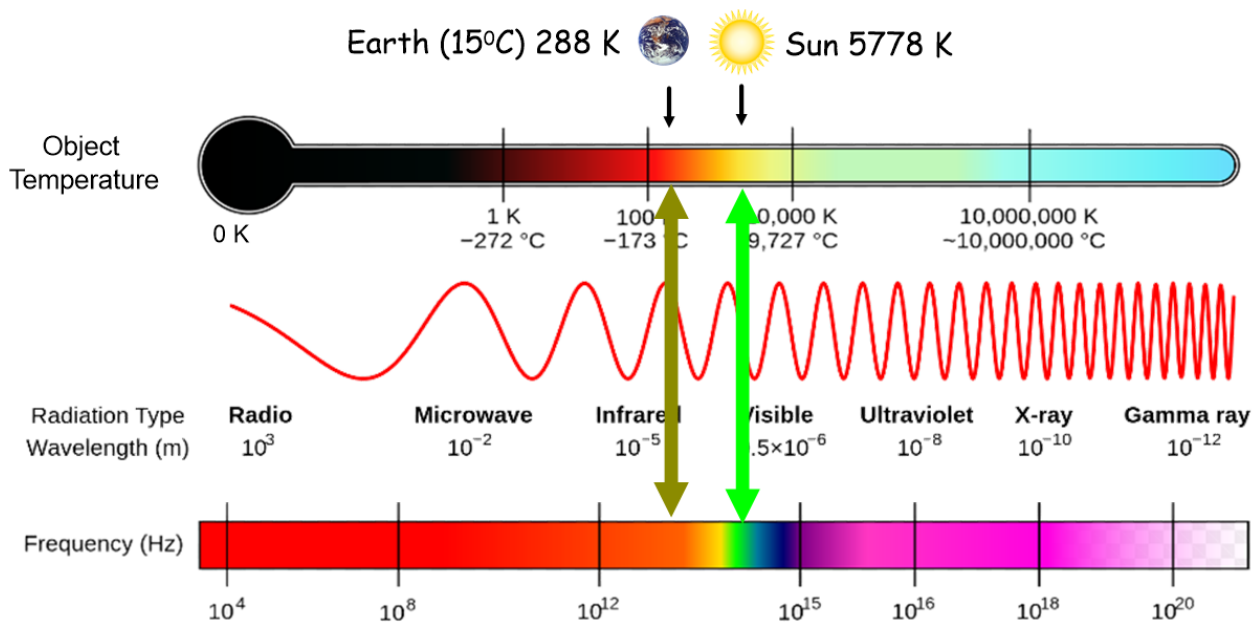
Linear and Logarithmic Scales (Continued)

On other **graphs** the horizontal axis represents **increasing wavelength**.



Sometimes the scale on the horizontal axis will be **linear** and sometimes it will be **logarithmic**. Be sure to check carefully.

Electromagnetic Radiation from the Sun and the Earth.



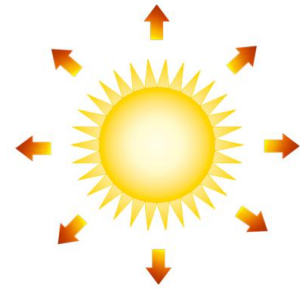
The most intense radiation from the **Sun** will be in the **visible** part of the electromagnetic spectrum. Wavelengths of the order of 10^{-6} m and frequencies of the order of 10^{14} Hz.

All of the radiation from the heated up **Earth** will be in the **infrared** region. Wavelengths of the order of 10^{-5} m.

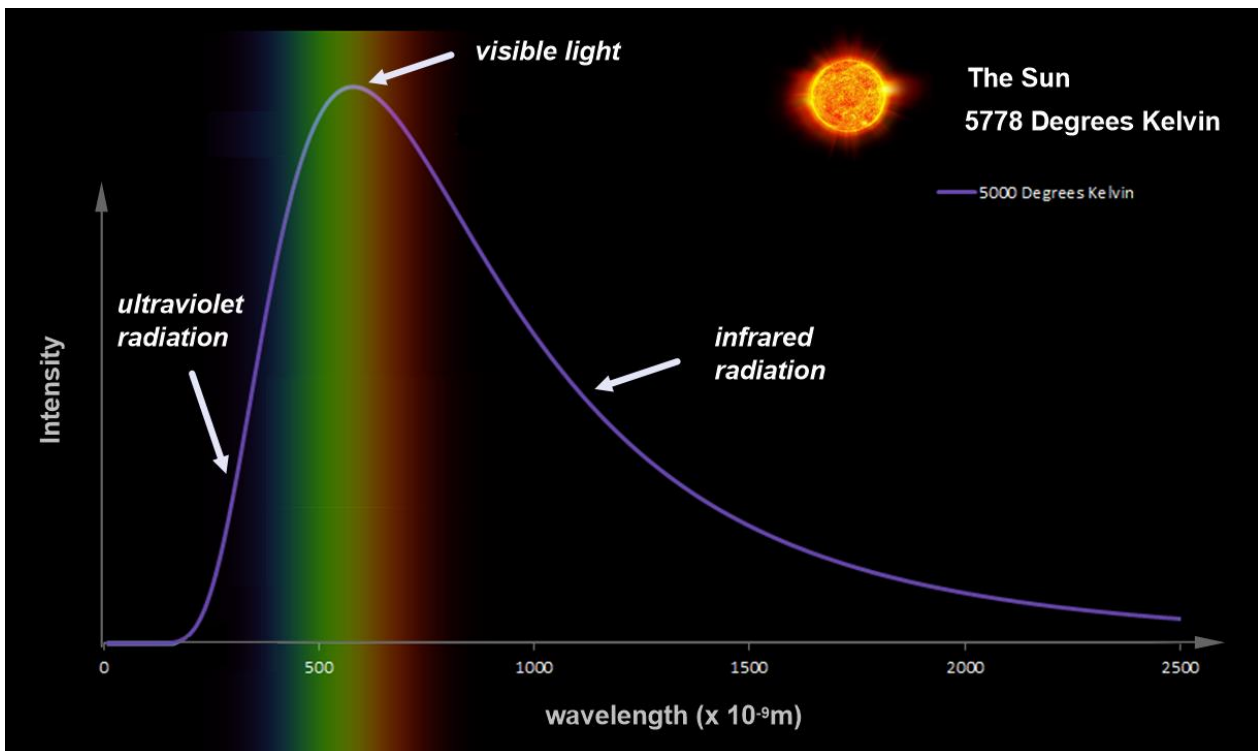
What do we know about **Electromagnetic radiation** from the **Sun**?

Curiously, the Sun can be modelled as a "**Black Body Radiator**".

It emits **B**..... **B**..... **R**.....



Intensity versus Wavelength graph showing **Black Body Radiation** for an object at 5000 K, a similar temperature to the surface of the Sun (5778 K)



The most intense radiation from the Sun will be in the visible part of the electromagnetic spectrum.

There will also be plenty of **infrared** radiation and some **ultraviolet** radiation.

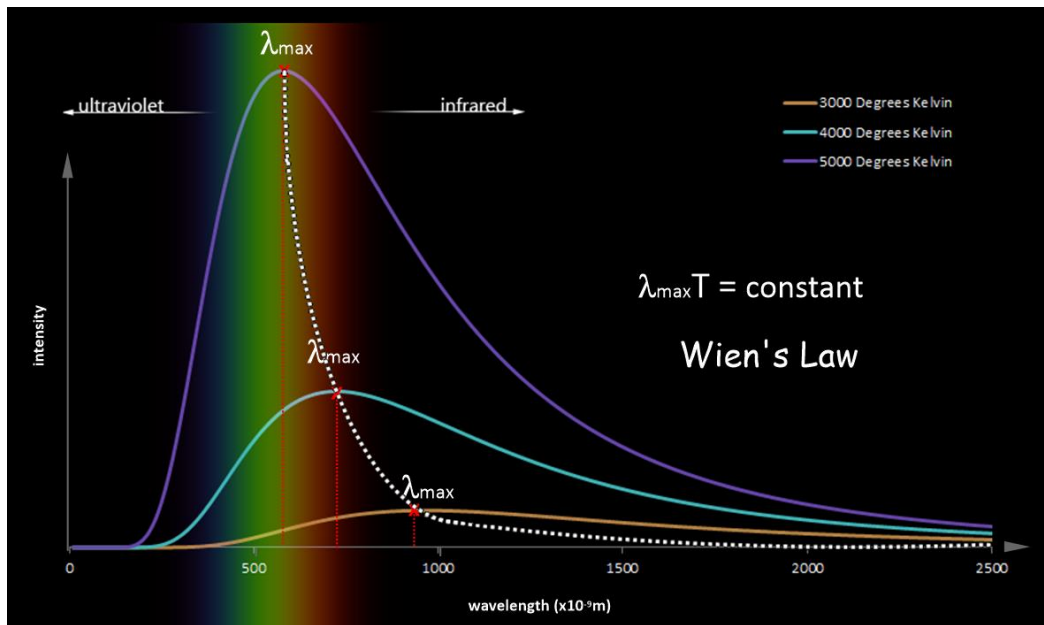
Extra Notes

Wien's Law

As the temperature of a black body radiator decreases, the intensity of its radiation also decreases.

however, the wavelength of intensity radiation, λ_{\max} , i.....

Mathematically this is expressed as $\lambda_{\max} T = \text{constant}$ and is known as Law



Wien's Law

$$\lambda_{\max} T = \text{constant}$$

Where

λ_{\max} = wavelength of maximum light intensity emitted by black body radiator at temperature T (m)

T = Temperature of black body radiator (K)

Wien's constant = 2.9×10^{-3} metre-Kelvin (mK)

The **earth** reflects visible light from the sun but emits no visible light of its own.

The earth can also be modelled as a black body radiator. Sun heats up the earth, raising its temperature, and as a result, radiation is re-radiated from the Earth.



Worked Example

- a** Use Wien's Law to determine the wavelength of maximum intensity radiation from the **Sun** given the sun's surface temperature is 5778 K.
- b** What part of the electromagnetic spectrum does this radiation come from?
- c** Use Wien's Law to determine the wavelength of maximum intensity radiation from the **Earth** given that the average surface temperature is 15°C.
- d** What part of the electromagnetic spectrum does this radiation come from?

The Power of Black Body Radiation

Power = rate of transfer of **energy** (Watts, W), that is, how energy is transferred from one type to another.

A 100 Watt light globe transfers electrical energy into heat and light energy as quickly as a 50 Watt globe and appears to be much b.....

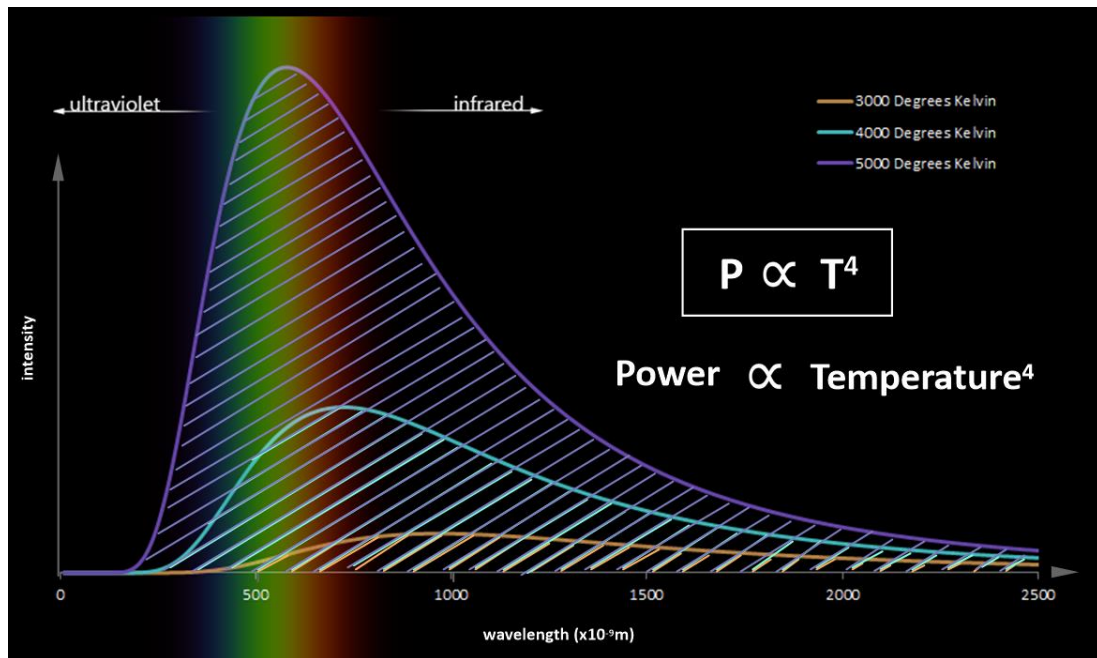


The concept of Power can be applied to radiated energy from a black body radiator, but units are Watts per s..... m.....

Power = rate of transfer of (Watts per square metre Wm^{-2})

Stefan Boltzmann Law

Power of a black body radiator is given by the area under the Intensity versus wavelength graph.



Stefan-Boltzmann Law

$$P \propto T^4$$

Power \propto Temperature⁴

or

$$P = \sigma T^4$$

Where

P = Power of thermal radiation from a black body radiator (Wm^{-2})

T = Temperature of black body radiator (K)

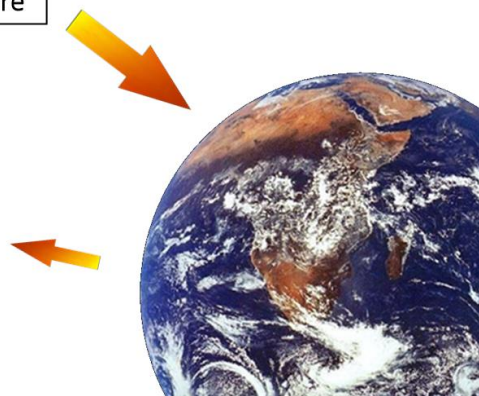
σ = Stefan-Boltzmann's constant = $5.67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$

What determines the Earth's surface temperature?

Radiation from Sun
Average Value = **340** Watts per square metre

Radiation reflected from Earth
Average Value = **100** Watts per square metre

$340 - 100 = 240$ Watts per square metre
absorbed by the earth!



For the Earth to be in thermal equilibrium, Watts would need to be re-radiated from the Earth's surface.

What temperature does this correspond to?

We can calculate this using the Stefan-Boltzmann Law



$$P = \sigma T^4$$

Worked Example

The earth can be modelled as a black body radiator, emitting thermal radiation at a rate of 240 Watts per square metre

a What temperature does this correspond to? Give your answer in K and in $^{\circ}\text{C}$.

b What type of Electromagnetic Radiation would this be?

Stefan-Boltzmann
prediction for earth's
surface temperature

-18°C

Actual average earth
surface temperature
since last ice-age

15°C

?

Why the big difference?

