Colour of Stars

Teachers' Notes

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Introduction

Throughout the universe, stars of many different sizes and colours exists. The colour of a star gives astrophysicists important information about the star, in particular its temperature.

This investigation is made up of several parts with increasing depth, investigating the phenomenon of heat radiation from objects. These investigations can help introduce discussion in the loss of heat energy from an object by radiation, the nature of heat itself, and the electromagnetic spectrum.

The different parts of this investigation slowly build in complexity.

- The first investigation is suitable for all year levels and abilities and involves watching a short, engaging video of thermal imaging of race cars, introducing the students to a visualisation of the heat lost from an object.
- The second investigation gives students a hands-on experience of heating an object until it starts to emit light. This can be used to talk about the electromagnetic spectrum as a continuum, and the idea that heat and light are both part of that spectrum.
- The third part again shows a short video clip, this time of a light bulb filament. Students are introduced to the concept that white light is a combination of all wavelengths. As we heat the filament, more visible wavelengths are emitted until the light becomes white.
- The final part is quite complex and is only intended for advanced classes or year 11-12. This part introduces blackbody radiation, showing the shape of the emitted radiation spectrum and giving a full explanation of the colour of light we see. Graph plotting and analysis is used.

The investigation could be halted after any part depending on year level and ability. The final conclusions about what the colour of a star tells us can be given no matter which stage is reached.

Part 1 – Racing Car

Question

What colours can you see with a thermal imaging camera and what do they mean?

In this first part, students watch two short videos. The race car subject matter should help to make the discussion more engaging. Analytical skills are exercised in identifying what the colours of a thermal imaging picture show us, and how the colours (heats) relate to the behaviour of the race car.

The videos give a clear visual picture of the heat radiated from objects, something we cannot normally see. The concept that the colour depends on the temperature is also introduced here.

Plan

Video1: The first video "*Red Bull Racing's RB8 Tearing it Up in Infrared*" (0:38) is linked on Youtube here:

https://www.youtube.com/watch?v=jvuBe6b2iVk

It shows a video of a racing car 'doing donuts' on the tarmac, taken by a thermal imaging camera.

Video2: The second video "*F1 2013 - Vettel Onboard Thermal in Suzuka*" (1:45) is linked on Youtube here:

https://www.youtube.com/watch?v=VNYUkRKslEw

It shows a 'drivers eye' view of a racing car, with the front wheels visible. Thermal imaging displays colours as the tires heat up going round the bends.

Conduct

Video1: Encourage the students to look at the different parts of the racing car, and surroundings. Students might note:

- how bright the tires are
- the trail left on the tarmac by the tires
- the 'flame' half way down the side of the car (exhaust)
- the difference in colour between tires and car body.
- the background is not coloured

Video2: Encourage the students to identify what the car is doing when the wheels change colour. Students might note:

- the tires are brightest when the car takes the bends
- the outside tire on the bend is brighter than the inside tire
- the tires are not so bright on the straight

Analysis

Video1: Two main parts of the car glow brightly yellow/white – the tires and the exhaust. Students should also notice that the trails of where the tires have been are clearly visible on the road.

Video2: The tires start off dark blue. When the car takes a bend, the outside tire changes colour to bright yellow, some yellow is also seen on the inside tire. As the car comes out into the straight again, the tires cool and their colour changes back to blue/purple.

Discussion

The footage from a thermal imaging camera shows us a "heat map". The camera records how hot something is, then shows us that information in colours so that we can see it, superimposed over a normal video image (this type of image is called a false colour image).

In this case the false colour shown corresponds to the temperature of the objects. As temperature changes from cold -> hot, colour changes from blue -> purple -> red -> orange -> yellow -> white.

Video1: most things in the image (the background) are not coloured. This means there is no heat information, they are relatively cold, at air temperature.
Two things are extremely hot – the exhaust gases coming out the side of the car (several hundred ^{o}C), and the tires. The rubber of the tires heats up due to friction with the road.

Where the road has been in contact with the tires, the tarmac also heats up – which you can see as the 'trails' left on the road surface as the car goes round.
Students can try guessing the temperature of each colour.

Video2: When the racing car starts its tires are cold, displayed by the thermal imaging camera as dark blue. As the car goes round a corner quickly, the weight of the car is thrown to the outside tire, which heats up (due to greater friction with the road) and glows brighter (yellow). When the car comes back to the straight the tires cool down to purple/blue.
When the car goes (relatively) slowly round a corner, only the inside tire heats a little, but does so assymetrically.

What is heat?
Heat is a form of energy. Heat energy travels from a hot object to anything colder. One of the ways heat energy can travel is by radiation.
A thermal imaging camera can show us the heat energy radiated from an object by colouring the image to show hot areas. We cannot see heat energy radiating from an object, but we can feel it if we hold our hand up close.

Conclusion

A thermal imaging camera colours areas of the picture that are hot. The hotter the object is, the brighter the colour. We cannot see this radiated heat normally. We can use thermal imaging cameras to show us things we cannot see with our eyes.

Part 2 – Heating Metal

Question

Investigate colour and temperature changes when heating nichrome wire.
This second part allows the students freedom to investigate the heating of an object to high temperatures themselves. The wire gives a nice demonstration of the continuity from emitting invisible heat to emitting visible light that we can see. This leads to discussion of the electromagnetic spectrum, and the fact that heat (infrared radiation) and light are parts of the same spectrum.

Plan

This investigation has been planned for you.

Conduct

Observe Bunsen burner safety rules.
Beware the wire will get very hot when held in the flame. The wire should be long and only the tip section needs to be in the flame.

The students may need to experiment to work out the best method to record the temperature of the wire, not of the flame itself.
Considerations:
The maximum temperature in a Bunsen burner flame is around 1550 C. However, students may not hold the wire in the hottest part of the flame. The wire will also cool very

quickly when taken out of the flame.

Analysis

Students should produce a table like the following:

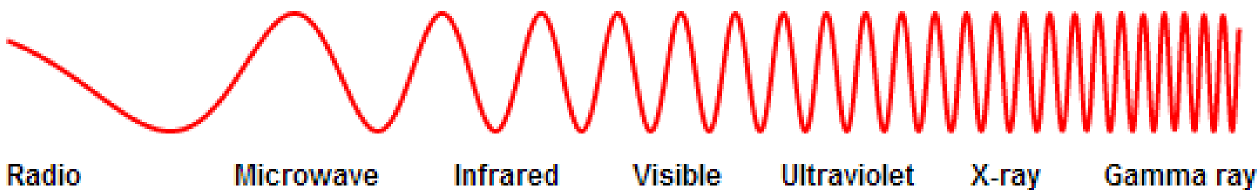
Temperature	Observations
Below about 600 ℃	Silver-coloured wire
About 600 – about 750	Dull red glow
About 750 – about 900	Brighter red glow (cherry red)
About 900 – about 1050	Bright orange
About 1050 – about 1200	Yellow
Above 1200	Yellow-white

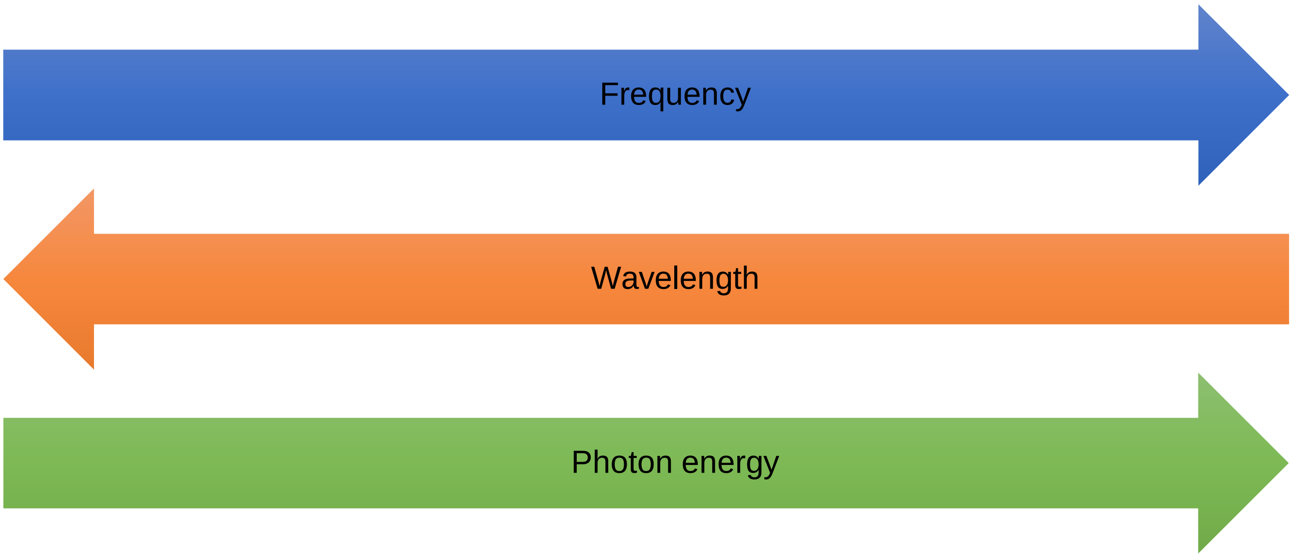
Discussion

1. *What happened to the piece of wire as its temperature was increased?*
   As the temperature of the wire increases, it will eventually start to glow. It will first glow red, then orange, then yellow, then white as it gets hotter. Note that the wire is still 'hot' once it starts glowing – it is still emitting heat.
2. *How do the conditions and results vary from the video of the racing car tires?*
   The wire is not pink or blue when cold – the thermal imaging camera shows false colour. The red-yellow-white colour sequence with increasing temperature is similar to what we saw with the racing car, but the actual temperatures for the wire are far higher than the racing car.
3. *If a piece of steel was to be heated to the same temperature as the nichrome wire, do you think it would look like the same colour?*
   Yes it will, because the colour depends on the temperature. Colour charts for how steel would look are available on the web, linking colour to temperature, for example: https://www.westyorkssteel.com/technical-information/steel-heat-treatment/hardening-temperatures/

As the wire is heated, we see it start to glow, which is to say it starts to emit visible light. Visible light is a type of electromagnetic radiation, just like radio waves, microwaves, infrared, ultraviolet, x-rays and gamma rays. These different names are given to electromagnetic waves depending on their different wavelengths, as shown in the diagram below.
Visible light spans from red light with the longest wavelength, through the colours of the rainbow to violet light with the shortest wavelength.
Infrared radiation is what we feel as 'heat' if we hold our hand up close to a warm object. It has a longer wavelength than visible light and we cannot see it with our eyes.

The electromagnetic spectrum





Conclusion

Heat and light are both electromagnetic radiation, but with different wavelengths. The colour of visible light also depends on its wavelength.

As the wire gets hotter it produces light. The colour of the light tells us how hot the wire is. We have just created a scale that we can use to read off the temperature if we know the colour.

Part 3 – Filament of an Incandescent Bulb

Question

What are the colour changes when an incandescent lightbulb turns on?
“Incandescent” means emitting light as a result of being heated.

Plan

This part is an open investigation into heating a lightbulb filament. Students are given basic equipment and asked to plan and conduct the experiment themselves.

As this is an open investigation, make sure the students cannot burn out the light bulb by accident by providing bulbs rated for the maximum voltage the student can supply e.g. for a 6V battery pack, the bulb should be rated 6V.
If the resistance that the rheostat is set to cannot be read from the component, provide resistance meters or treat this as a qualitative exercise (“high/med/low” resistance).

<Alternative>
If time is short or equipment is not available, you could show this video clip from Youtube instead: “Slow-Motion video of Bulb Glowing” (0:48) Actual lightbulb lighting is from 0:14 – 0:28s

https://www.youtube.com/watch?v=zoE5M5W4enI

There are some alternatives available:
“Glowing Halogen Bulb (Slow-Motion Videos)” (0:37)

https://www.youtube.com/watch?v=_VMz9Pnbr98

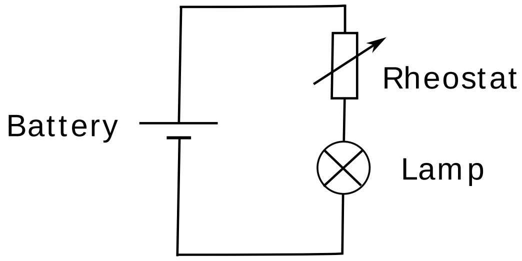
“Lightbulb Loop” (0:31)
https://www.youtube.com/watch?v=UjB7sAZL5Fo
“SLOW-MO : Light Bulb Turning On and Off” (0:44)
https://www.youtube.com/watch?v=N-ZWh1O_BZ0

Conduct

Students need to work out what colours they expect to see and how to record the colours. The nichrome wire experiment and discussion in Part 2 should lead them to writing a colour scale like dull red -> red -> orange -> yellow -> white. Students should record the voltages corresponding to these colours (if they can get fine enough control to separate them all).

Analysis

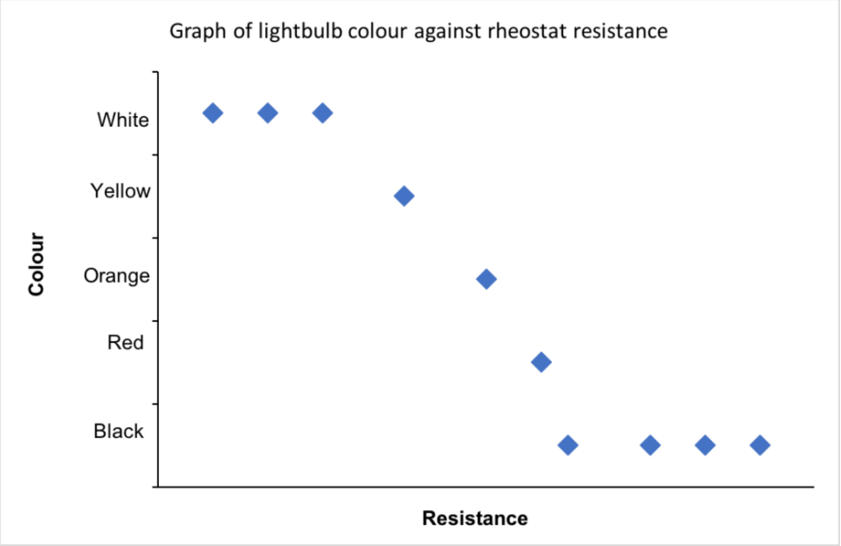
The students will need to connect a circuit like this:



Varying the resistance of the rheostat will vary the current in the circuit. If the rheostat has a high resistance, there will only be a low current and the lamp will be very dim. If the rheostat has virtually no resistance, the lamp will light brightly.

The lamp starts off ‘cold’ (at room temperature) when there is no current flowing through it. When current starts to flow, the filament heats up. As the temperature of the filament increases, it will start to glow, just like the nichrome wire in the previous experiment. It will first glow red, then orange, then yellow, then white as it gets hotter.

Students could plot a graph of their data something like this if they can get enough points:



Discussion

If the students are not familiar with an incandescent light bulb, discuss its operation. The bulb contains a ‘filament’ – a very thin piece of wire. An electric current passes through it and causes the wire to heat up. It gets so hot that it glows brightly.

1. *In part 2 you have discussed the electromagnetic spectrum with your teacher. You may already know that white light is made up of a mixture of different wavelengths of light. Considering this and the fact that the light bulb in the clip produced a white light, is the electromagnetic radiation emitted from objects ever just one wavelength?*
   When the bulb is hot, the light appears to be white in colour. This must mean the filament is emitting a mixture of wavelengths.
   When glowing brightly, the light bulb is emitting over a range of wavelengths, which still includes the infrared part of the spectrum. If you could put your hand near the filament it would feel very hot! A thermal imaging camera would be able to show us this.
2. *What energy changes are happening here?* First think about what is happening before the lightbulb starts to glow. Electrical energy from the power supply is converted to thermal energy in the filament. Heat is a form of energy.

Conclusion

The filament of a bulb glows red, then orange, yellow, white. This is similar to the nichrome wire.
Heat energy radiated from a hot object is electromagnetic radiation emitted with a range of wavelengths.

<Extension understanding>
At room temperature, heat energy radiated will be mostly low infrared and we see nothing. As we start to heat up the object, the radiation emitted is a mixture of infrared up to red visible light – we cannot see infrared so the object looks red. As temperature increases, the range emitted shifts to shorter wavelengths, and the average wavelength emitted shifts to orange and then yellow light. Eventually the wavelengths emitted cover the whole visible spectrum and so the light looks white.

Part 4 – Blackbody Radiation Simulation (Advanced Classes/Yr11-12)

Question / Aim

Use a computer simulation to investigate radiation emitted by hot objects. This is called “Blackbody Radiation”.

Plan

Use the Blackbody Spectrum Simulator available at
https://phet.colorado.edu/en/simulation/legacy/blackbody-spectrum

Use the following table of colour, temperature and mass values of a range of different stars found in our galaxy, the Milkyway

Star	Colour	Temperature (^oC)	Mass of star (in solar masses)

Sun	Yellow	5,700	1
Proxima Centauri	Red	2,300	0.1
Barnard's Star	Red	3,000	0.1
Epsilon Eridani	Orange	4,600	0.1
Alpha Centauri	Yellow	6,000	1
Altair	White	8,000	3
Vega	White	9,900	3
Sirius	White	10,000	3
Rigel	White	10,000	3
Regulus	White	11,000	8
Hadar	Blue	25,500	20
Alnilam	Blue	27,000	20

Conduct

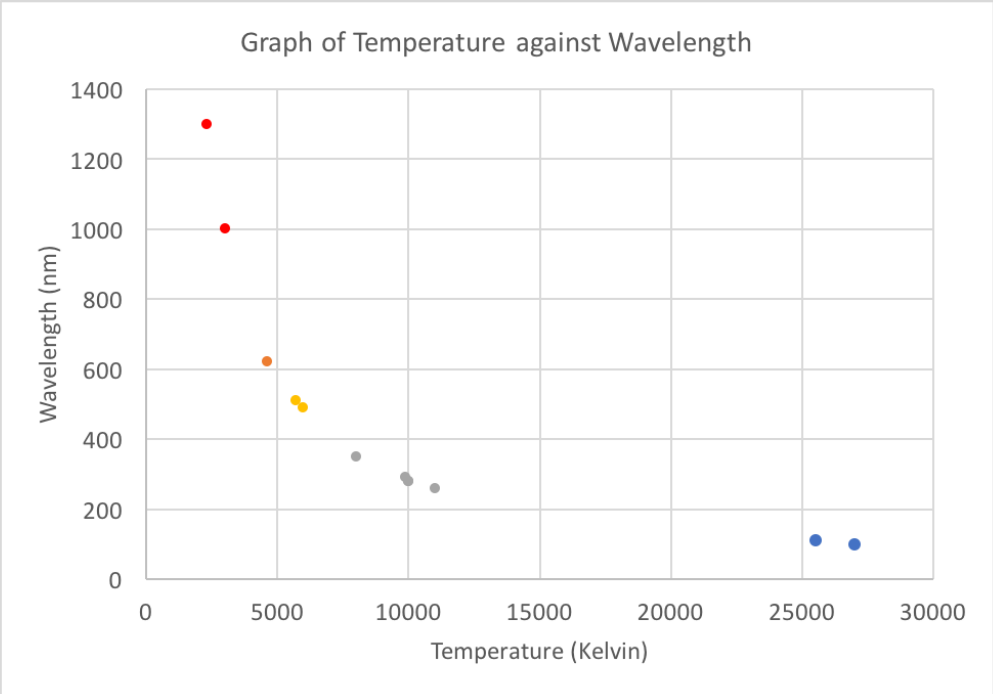
Use the (+) and (-) zoom tools on both axes so you can see the whole shape of the spectrum at different temperatures.
You can type a temperature value into the box displaying the temperature.

Completed table should look like this:

Star	Colour	Temperature (^{o}C)	Mass of star (in solar masses)	Wavelength (nm)
Sun	Yellow	5,700	1	510
Proxima Centauri	Red	2,300	0.1	1300
Barnard's Star	Red	3,000	0.1	1000
Epsilon Eridani	Orange	4,600	0.1	620
Alpha Centauri	Yellow	6,000	1	490
Altair	White	8,000	3	350
Vega	White	9,900	3	290
Sirius	White	10,000	3	280
Rigel	White	10,000	3	280
Regulus	White	11,000	8	260
Hadar	Blue	25,500	20	110
Alnilam	Blue	27,000	20	100

Analysis

The plotted star temperature against colour should look like the following (with the star names labelled):



Discussion

1. *From the graph, what is the relationship between the temperature and the colour of stars?*
   As the temperature increases, the colour changes from Red -> Orange -> Yellow -> White -> Blue and the wavelength decreases. Students should be able to clearly see the decrease is a curve, not a straight line. Some may recognise the graph shape as being 1/x (difficult to distinguish visually from e^{-x} though). See Wiens Law below for further discussion for advanced students.
2. *Looking at the table, what is the relationship between temperature, colour and mass of stars?*
   The mass goes up with the colour progression, just as the temperature does. Mass and temperature are linked.

Using the equations, $c = f\,\lambda$ and also $E = h\,f$
, where *c* is the speed of light, λ is the wavelength, *f* is the frequency, *E* is the photon energy, and *h* is planks constant, and referring to the electromagnetic spectrum diagram above, we can determine that:

As the temperature increases, the frequency of electromagnetic radiation emitted…

…..**increases**.

As the temperature increases, the wavelength of electromagnetic radiation emitted…

…..**decreases**.

As the temperature increases, the photon energy of electromagnetic radiation emitted…

….**increases**.

The term 'blackbody'
Students should have experienced that black objects heat up in the sun faster than white

objects. This is because black objects absorb light at all wavelengths while white objects do not, instead reflecting it back. The same is true for emission of electromagnetic radiation – black objects can also emit at all wavelengths. In physics, a 'black body' is a theoretical perfect object that can emit or absorb radiation freely at all wavelengths.

<Extension>
More advanced students may study in more detail the relationship between wavelength and temperature:

The peak wavelength of the blackbody radiation spectrum at a given temperature is given by Wien's Law:

$$f_{max} \propto T \quad or \quad \lambda_{max} \propto \frac{1}{T}$$

The Wavelength vs Temperature graph should therefore give us a 1/x shape. As a check, if you multiply each wavelength and temperature in the table together these should give you a constant value.

FINAL CONCLUSION

When an object is hot enough, it starts to glow, first red, then yellow, then white, then blue as it gets hotter. We can do experiments to find out what temperatures these colours correspond to. We then know the temperature of an object just by looking at the colour of light it emits.
The same concept applies to the colour of light that we see when we look at a star. The colour can be used to tell us the temperature of the star!

Astrophysicists have found that the temperature of a star is also related to its size. We can observe that larger stars tend to be hotter. This sort of information helps scientists develop theories and models about star formation and the lifecycle of stars.