Intro to Quantum Physics F3241

Dr Lily Asquith (Lily)

Week 3

Blackbody Radiation

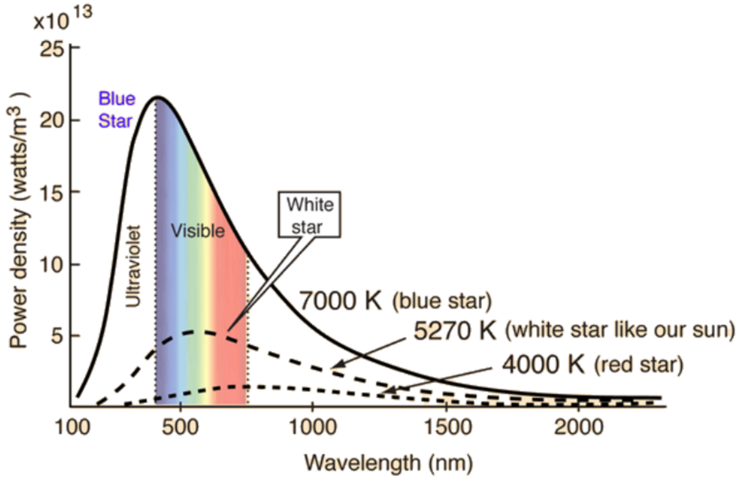
This week's topics:

3.1 Blackbody Radiation

3.2 The Ultraviolet Catastrophe, Planck to the rescue

Your homework questions for this week are on canvas - please complete these by the end of the week.

Temperature: observations



Let's do a quiz: pollev.com/ilovephysics

Wien's Law & Stefan-Boltzman Law

The Peak Wavelength $\lambda_P \sim T^{-1}$.

Wien's law: $\lambda_P = \sigma T^{-1}$, where $\sigma = 2.90 \times 10^{-3}$ [units?]

The Peak Power Density $R_P \sim T^4$.

Stefan-Boltzman Law: $R_P = kT^4$, where $k = 5.67 \times 10^8$ Wm^{-2}

Note that astronomers use really silly units.

Silly Astronomers

From Wikipedia: Radiant_intensity with a page search for "confusing":

Radiance	$L_{e,\Omega}$[nb 5]	watt per steradian per square metre	W·sr^{-1}·m^{-2}	M·T^{-3}	Radiant flux emitted, reflected, transmitted or received by a *surface*, per unit solid angle per unit projected area. This is a *directional* quantity. This is sometimes also confusingly called "intensity".
Spectral radiance	$L_{e,\Omega,\nu}$[nb 3]	watt per steradian per square metre per hertz	W·sr^{-1}·m^{-2}·Hz^{-1}	M·T^{-2}	Radiance of a *surface* per unit frequency or wavelength. The latter is commonly measured in W·sr^{-1}·m^{-2}·nm^{-1}. This is a *directional* quantity. This is sometimes also confusingly called "spectral intensity".
	$L_{e,\Omega,\lambda}$[nb 4]	watt per steradian per square metre, per metre	W·sr^{-1}·m^{-3}	M·L^{-1}·T^{-3}	
Irradiance Flux density	E_e[nb 2]	watt per square metre	W/m^2	M·T^{-3}	Radiant flux *received* by a *surface* per unit area. This is sometimes also confusingly called "intensity".
Spectral irradiance Spectral flux density	$E_{e,\nu}$[nb 3]	watt per square metre per hertz	W·m^{-2}·Hz^{-1}	M·T^{-2}	Irradiance of a *surface* per unit frequency or wavelength. This is sometimes also confusingly called "spectral intensity". Non-SI units of spectral flux density include jansky (1 Jy = 10^{-26} W·m^{-2}·Hz^{-1}) and solar flux unit (1 sfu = 10^{-22} W·m^{-2}·Hz^{-1} = 10^4 Jy).
	$E_{e,\lambda}$[nb 4]	watt per square metre, per metre	W/m^3	M·L^{-1}·T^{-3}	
Radiosity	J_e[nb 2]	watt per square metre	W/m^2	M·T^{-3}	Radiant flux *leaving* (emitted, reflected and transmitted by) a *surface* per unit area. This is sometimes also confusingly called "intensity".
Spectral radiosity	$J_{e,\nu}$[nb 3]	watt per square metre per hertz	W·m^{-2}·Hz^{-1}	M·T^{-2}	Radiosity of a *surface* per unit frequency or wavelength. The latter is commonly measured in W·m^{-2}·nm^{-1}. This is sometimes also confusingly called "spectral intensity".
	$J_{e,\lambda}$[nb 4]	watt per square metre, per metre	W/m^3	M·L^{-1}·T^{-3}	
Radiant exitance	M_e[nb 2]	watt per square metre	W/m^2	M·T^{-3}	Radiant flux *emitted* by a *surface* per unit area. This is the emitted component of radiosity. "Radiant emittance" is an old term for this quantity. This is sometimes also confusingly called "intensity".
Spectral exitance	$M_{e,\nu}$[nb 3]	watt per square metre per hertz	W·m^{-2}·Hz^{-1}	M·T^{-2}	Radiant exitance of a *surface* per unit frequency or wavelength. The latter is commonly measured in W·m^{-2}·nm^{-1}. "Spectral emittance" is an old term for this quantity. This is sometimes also confusingly called "spectral intensity".
	$M_{e,\lambda}$[nb 4]	watt per square metre, per metre	W/m^3	M·L^{-1}·T^{-3}	

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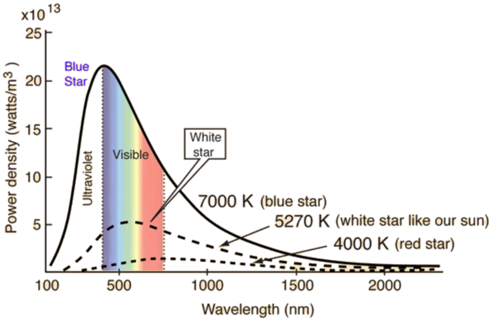
Energy Density: The Rayleigh-Jeans law

We can understand the blackbody spectrum in pieces, but what about the whole thing?



R-J Law: $U(T) = \frac{8\pi}{\lambda^4} k_B T$

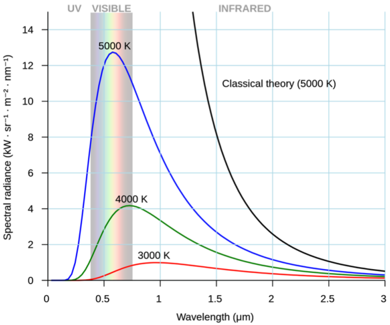
where

$k_B = 1.38 \times 10^{-23}\ \mathrm{JK}^{-1}$

Let's analyse this...

The UV catastrophe: Aargh!

Classical Physics has failed us!



R-J Law: $U(T) = \frac{8\pi}{\lambda^4} k_B T$

where

$k_B = 1.38 \times 10^{-23}$ JK^{-1}

Let's analyse this...

Relating Frequency, Wavelength, Speed

The wavelength λ

The frequency f

The speed c

Planck's "Solution"

R-J Law: $U(T) = \frac{8\pi}{\lambda^4} k_B T$

Does not agree with countless observations

The theory (classical) to be modified somehow if it is to describe the data

Planck found that if he insisted **the energy only take discrete values**, he got this modification for free.

Allowed Energy $E =$ [some integer n] x [some constant h] x [frequency]

Planck Law: $U(T) = \frac{8\pi}{\lambda^4} \frac{hc}{\lambda(e^{(hc/\lambda)k_B T} - 1)}$

This Planck formula of the 'energy density' perfectly matched the observations, and solved the UV catastrophe.

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Allowed Energies

Allowed Energy $E = [\text{n}] \times [\text{h}] \times [\text{f}] = [\text{n}] \times [\text{h}] \times [\ \frac{c}{\lambda}\ ]$

Consider three wavelengths of em radiation:

10 m (radio)
500 nm (visible light)
100 pm (x-ray)

If $hc = 1240$ eV nm, what is the smallest $(n = 1)$ allowed energy in eV?

Note!

Planck did not think his restriction of Energies using E=nhf was anything more than a mathematical trick.

It was Einstein who realised the physical importance of this, and coined the term 'Planck's constant' for h.

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