B.2

Radiation from the Sun

IB PHYSICS | ASTROPHYSICS

Intensity

B.2

$$Intensity = \frac{Power}{A}$$

When talking about the intensity of light from stars, this is often referred to as **brightness**

$$Units = \frac{W}{m^2} = Wm^{-2}$$

Remember Brightness?

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As light travels away from a point source it spreads out in a sphere in all directions so the area is that of the shell of this sphere with a radius equal to the distance from the source

Remember the surface area of a sphere?

$$A_{sphere} = 4\pi r^2$$

Equation Reminders

B.2

B.1 Thermal energy transfers	

$$\rho = \frac{m}{V}$$

$$\overline{E_k} = \frac{3}{2} k_B T$$

$$Q = mc\Delta T$$

$$Q = mL$$

$$\frac{\Delta Q}{\Delta t} = kA\frac{\Delta T}{\Delta x}$$

$L = \sigma A T^4$ ← Luminosity

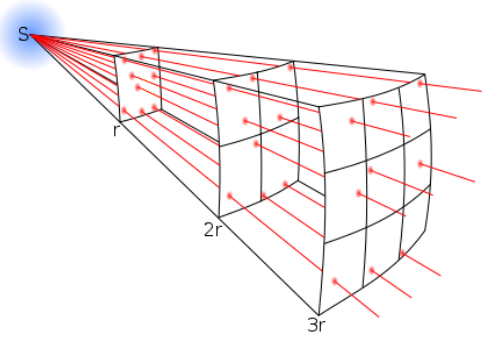
$b = \frac{L}{4\pi d^2}$ ← Brightness

$\lambda_{max} T = 2.9 \times 10^{-3}\,\text{mK}$ ← Temperature

B.2

Intensity

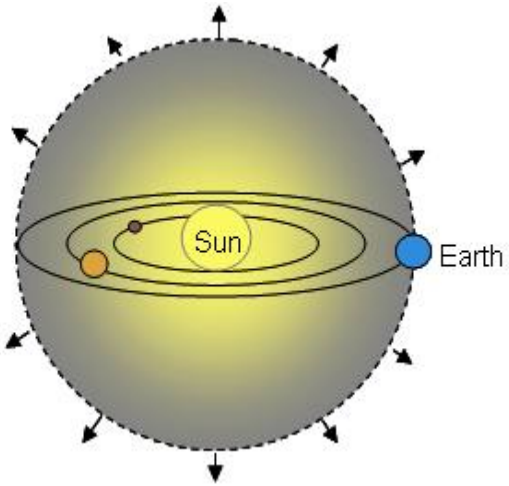
Calculate the intensity of the Sun's radiation arriving to Earth



Sun's Power = 3.84×10^{26} W

Earth's Distance from Sun = 150×10^{6} km

$$b = \frac{L}{4\pi d^2} = \frac{3.84 \times 10^{26}}{4\pi(150 \times 10^{9})^2}$$



$$Intensity = b = 1358\ \mathrm{Wm^{-2}}$$

Solar Constant

B.2

The average intensity falling on an area above the earth's atmosphere perpendicular to the direction traveled by the radiation

$$S = 1358\ \text{W m}^{-2} \approx 1.36 \times 10^{3}\ \text{W m}^{-2}$$

Quantity	Symbol	Approximate value
Acceleration of free fall	g	$9.8\,\text{m s}^{-2}$ (Earth's surface)
Electron rest mass	m_e	$9.110\times10^{-31}\,\text{kg} = 0.000549\,\text{u} = 0.511\,\text{MeV c}^{-2}$
Proton rest mass	m_p	$1.673\times10^{-27}\,\text{kg} = 1.007276\,\text{u} = 938\,\text{MeV c}^{-2}$
Neutron rest mass	m_n	$1.675\times10^{-27}\,\text{kg} = 1.008665\,\text{u} = 940\,\text{MeV c}^{-2}$
(Unified) atomic mass unit	u	$1.661\times10^{-27}\,\text{kg} = 931.5\,\text{MeV c}^{-2}$
Solar constant	S	$1.36\times10^{3}\,\text{W m}^{-2}$
Fermi radius	R_0	$1.20\times10^{-15}\,\text{m}$

Average Solar Intensity on Earth

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Earth's Radius = 6.37×10^6 m

Area of sun power captured:

$$\pi r^2 = \pi(6.37 \times 10^6)^2 =$$

$$1.27 \times 10^{14}\ \text{m}^2$$

1360 W m^{-2}

Total sun power captured:

$$1.27 \times 10^{14}\ \text{m}^2 \times \frac{1360\ \text{W}}{1\ \text{m}^2} =$$

$$1.7 \times 10^{17}\ \text{W}$$

Average spread out across Earth's surface:

$$\frac{P}{A_{sphere}} = \frac{1.7 \times 10^{17}\ \text{W}}{4\pi(6.37 \times 10^6)^2} =$$

$$340\ \text{W m}^{-2}$$

Total Power Received by the Earth

$$1.7 \times 10^{17}\ \text{W}$$

Average Solar Intensity on Earth

$$340\ \text{W m}^{-2}$$

Shortcut time!

$Average = 340\ \mathrm{W\ m^{-2}}$

The energy is captured by a disc with an area of πr^2

and averaged out over a surface area of $4\pi r^2$

$$1360 \times \frac{\cancel{\pi r^2}}{\cancel{4\pi r^2}} = \frac{1360}{4} = \mathbf{340\ W\ m^{-2}}$$

Thermal Equilibrium

B.2

In order to maintain a constant global temperature, the Earth must emit the same amount of energy that it absorbs

Captured energy from the sun

$340\ W\ m^{-2}$

$340\ W\ m^{-2}$

Energy that is reflected or reemitted as heat

Emissivity

B.2

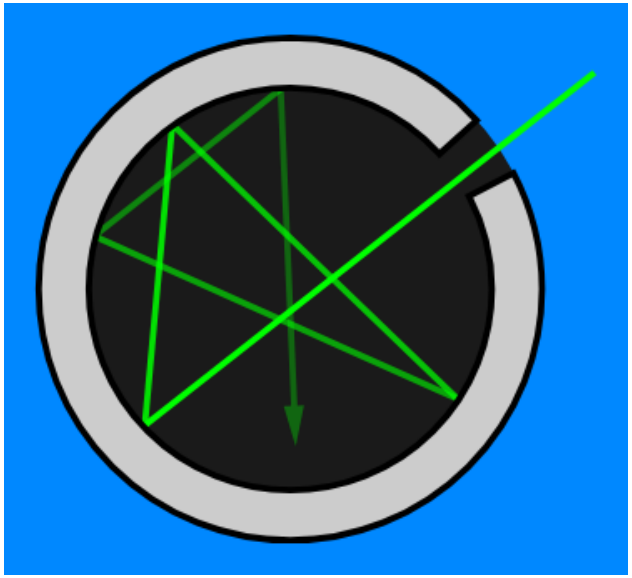
What color car heats up the most in the sun?

Black – Absorbs more light

Black Body Radiator

B.2

A black body radiator is an object that is perfectly opaque and absorbs all energy



Conceptual Black Body

This also represents an object that is most efficient at radiating energy when it heats up

"Grey Bodies"

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There are many objects that aren't perfect black body radiators and emit less energy per second at the same temperature/size

Black Body

$e = 1$

Grey Body

$e < 1$

The amount of energy emitted by a grey body can be quantified through the ratio known as emissivity

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Emissivity

Emissivity	e	$\frac{power\ radiated\ by\ a\ surface}{power\ radiated\ from\ a\ black\ body\ of\ the\ same\ temperature\ and\ area}$

The emissivity is used to adjust for an object that isn't a perfect black-body radiator

This value is always between 0 and 1

$e \approx 1$

$e \approx 0.6$

Emissivity

The luminosity equation from topic B1 assumes black body radiation so emissivity can be added if it is not an ideal radiator

$$L = \sigma A T^4$$

Assumes that the object is a black body radiator

$$e = 1$$

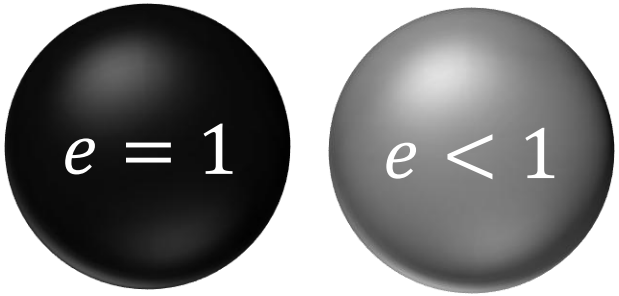
emissivity = 1 if it is a black body radiator and emissivity < 1 if in other cases

Emissivity

$$L = e\sigma AT^4$$

$$e = \frac{L}{\sigma AT^4}$$

L → Power radiated per unit area



$$e = \frac{power\ radiated\ per\ unit\ area}{\sigma T^4}$$

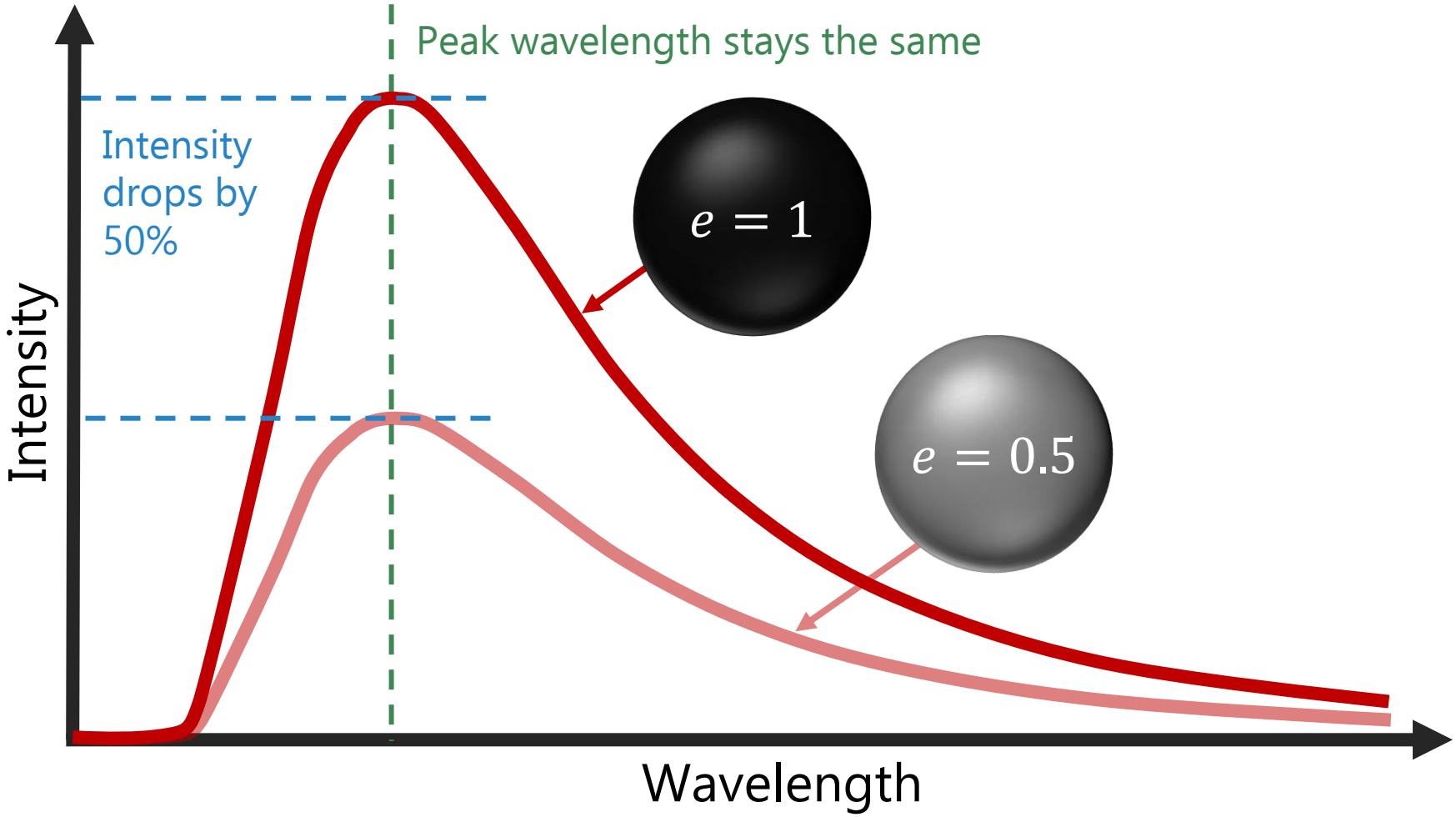
IB Physics Data Booklet

B.2

B.2 Greenhouse effect	$\text{emissivity} = \dfrac{\text{power radiated per unit area}}{\sigma T^4}$ $\text{albedo} = \dfrac{\text{total scattered power}}{\text{total incident power}}$

Emissivity

B.2

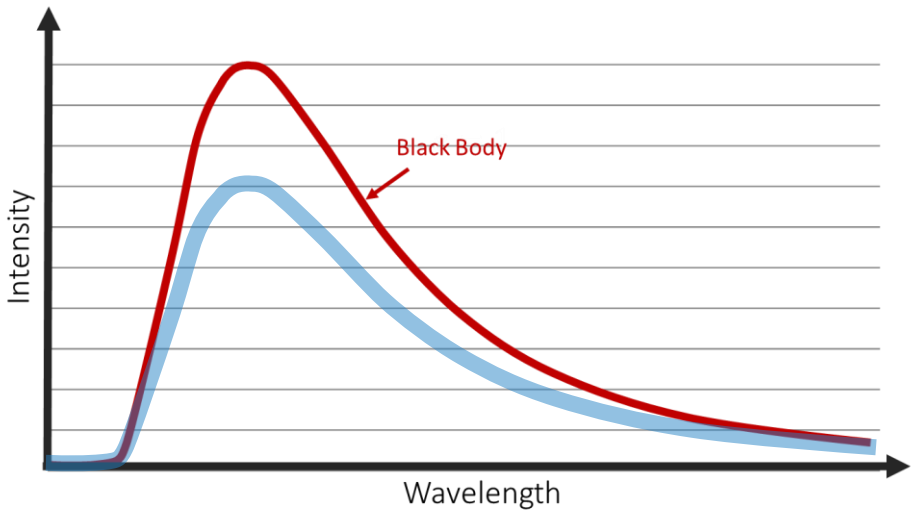


Try This…

A body with a temperature of 370 K and a surface area of 0.8 m^2 radiates 600 J of energy each second (600 W). Calculate the emissivity of the body and sketch its intensity vs wavelength graph

$$e = \frac{600}{(5.67 \times 10^{-8})(0.8)(370)^4}$$

$$e = 0.705$$



Stefan-Boltzmann Constant	σ	5.67×10^{-8} W m^{-2} K^{-4}

B.2

IB Physics Data Booklet

B.2 Greenhouse effect	$\text{emissivity} = \dfrac{\text{power radiated per unit area}}{\sigma T^4}$ $\text{albedo} = \dfrac{\text{total scattered power}}{\text{total incident power}}$

Albedo → Ratio quantifying how reflective a surface is

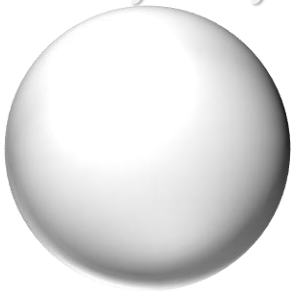
Black Body

$albedo = 0$

Grey Body

$0 < albedo < 1$

Shiny Body



$albedo \approx 1$

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Albedo vs Emissivity

Albedo
$\frac{total\ scattered\ power}{total\ incident\ power}$

Emissivity	e
$\frac{power\ radiated\ per\ unit\ area}{\sigma T^4}$	

% Reflected

% Absorbed

Note: in reality, the light reflected by the earth is at a very different wavelength than the light emitted so these values don't always relate mathematically like this

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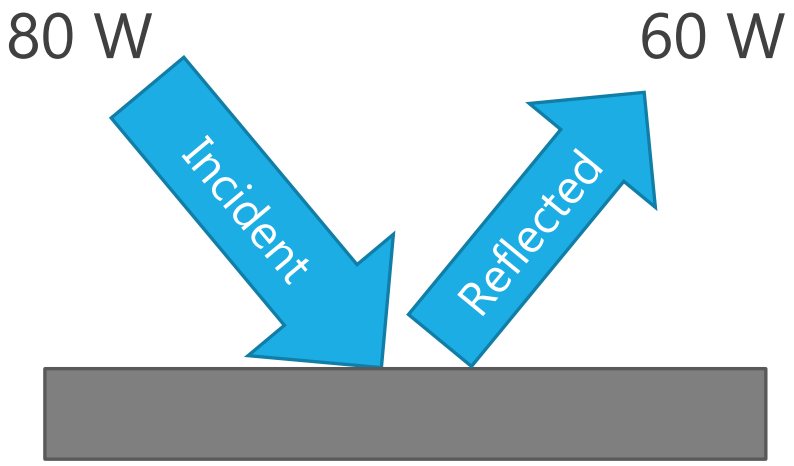
Albedo vs. Emissivity



Albedo

$$\frac{60}{80} = 0.75$$

Emissivity

$$\frac{20}{80} = 0.25$$

Albedo of Earth

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$$Albedo = \frac{102}{340} = 0.3$$

Albedo of Earth

Highest Albedo?

0.66

Snow

Lowest Albedo?

0.07

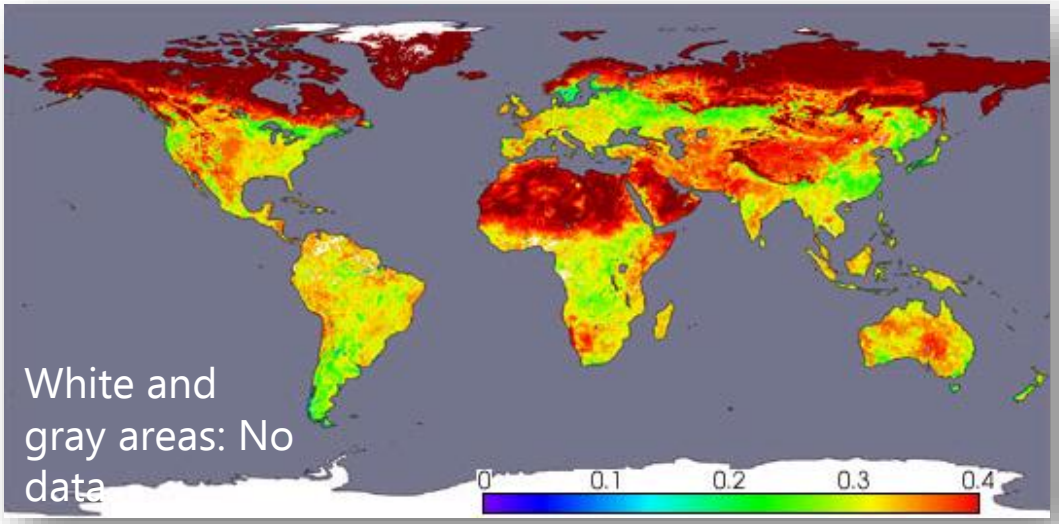
Ocean

Surface	Albedo[a]	
	Summer	Winter
Mixed farming, tall grass	0.16	0.18
Tall/medium grassland, evergreen shrubland	0.20	0.21
Short, grassland, meadow and shrubland	0.21	0.20
Evergreen forest (needle leaved)	0.12	0.13
Mixed deciduous, evergreen forest	0.16	0.16
Deciduous forest	0.17	0.18
Tropical evergreen broadleaved forest	0.12	0.15
Medium/tall grassland, woodland	0.15	0.18
Desert	0.36	0.36
Tundra	0.17	0.17
Snow	0.66	0.66
Sea ice	0.62	0.62
Ocean	0.07	0.07

Data taken from Briegleb *et al.* (1986).

Albedo of Earth

B.2



April, 2002, *Terra* satellite, NASA

Surface

Atmosphere

Since cloud formations change daily, the albedo of earth is constantly fluctuating

Adjusting our Albedo

B.2

BUREAU OF STREET SERVICES

Los Angeles paints streets white to stay cool

By David Shultz | Sep. 7, 2017 , 5:00 PM

LA Street Services
@BSSLosAngeles

Today Los Angeles became the first place in California to install a cool pavement treatment on a public street! Ten deg cooler on summer aft

12:54 PM - May 20, 2017

196 124 people are talking about this

B.2

Thermal Equilibrium

In order to maintain a constant global temperature, the Earth must emit the same amount of energy that it absorbs

Captured energy from the sun

$340\ W\ m^{-2}$

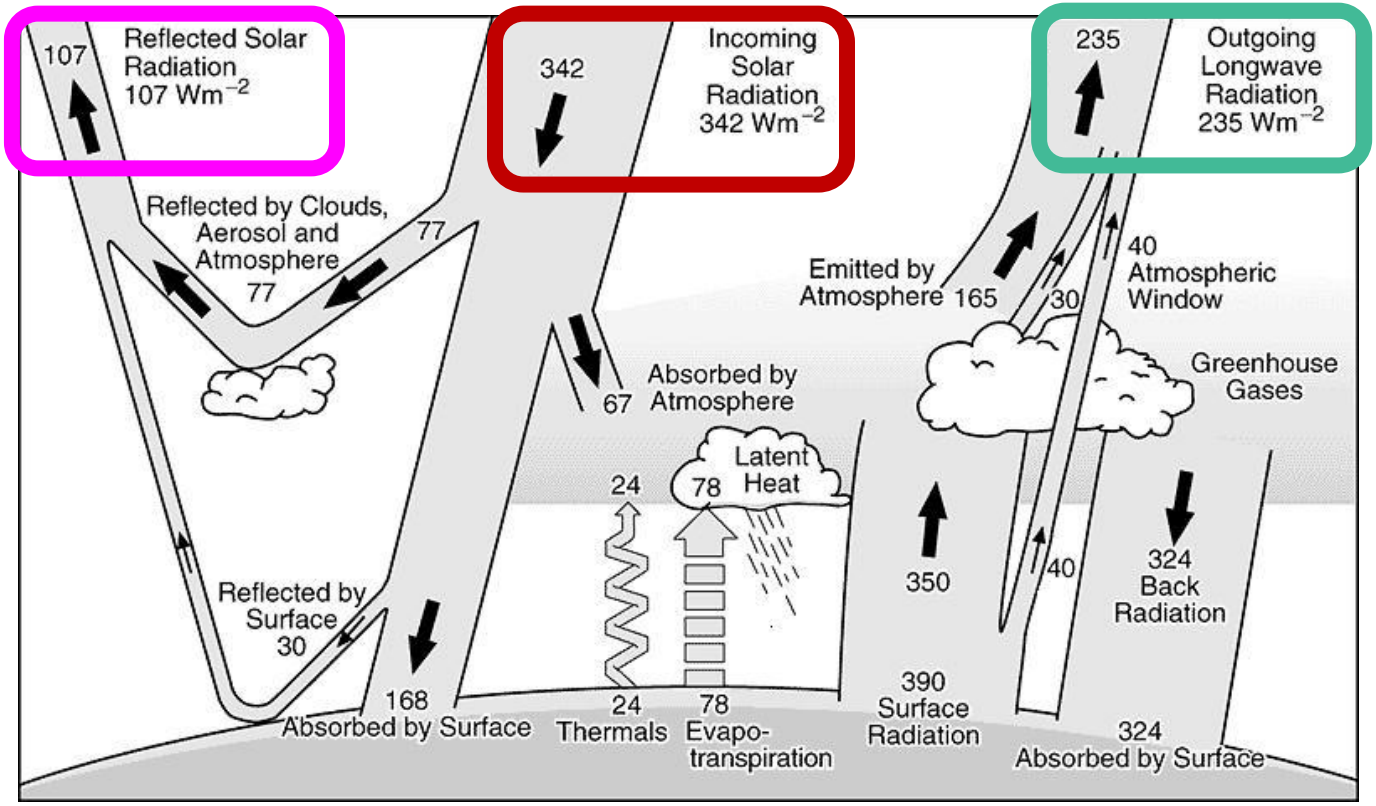
$340\ W\ m^{-2}$

Energy that is reflected or reemitted as heat

Albedo Emissivity

B.2

Thermal Equilibrium



(in) **342 W m^{-2} = 342 W m^{-2}** (out)

Lesson Takeaways

B.2

- ❑ I can define intensity with proper units
- ❑ I can describe how intensity changes according to the surface area of a sphere
- ❑ I can derive the Solar Constant from the sun's power and distance from earth
- ❑ I can calculate the average solar intensity on earth from the solar constant and earth's radius
- ❑ I can compare the properties of albedo and emissivity