IPOL 8512 Midterm Review

Fall 2012

Requested Topics

- Energy and Power calculations

$$\text{power} = \frac{\text{energy}}{\text{time}} \qquad \text{Watt (W)} = \frac{\text{joule (J)}}{\text{second (s)}}$$

$$\text{energy} = \text{power} \times \text{time} \qquad \text{J} = \text{W}\cdot\text{s}$$

common energy units: J, cal, Cal, kWh, Btu, quad

$1\ \text{cal} = 4.184\ \text{J}$

$1\ \text{Cal} = 4184\ \text{J}$

$1\ \text{kWh} = 3.6\ \text{MJ}$

$1\ \text{Btu} = 1055\ \text{J} = 1.055\ \text{kJ}$

$1\ \text{quad} = 10^{15}\ \text{Btu} = 1.055\ \text{exajoule (EJ)} = 1.055 \times 10^{18}\ \text{J}$

Requested Topics

Mass ice ⇌ volume ice
or Mass liquid water ⇌ volume liquid water

- The conversion of mass to volume or volume to mass is done with density.

$$\text{density} = \frac{\text{mass}}{\text{volume}} \qquad \frac{1.0\text{ g liquid water}}{1\text{ mL}} \qquad \frac{0.92\text{ g ice}}{1\text{ mL}}$$

Requested Topics

- W (solar irradiance) $\rightleftharpoons$ m^2

Solar energy flux striking top of atmosphere, averaged over whole surface area of earth

$$\frac{342\ \text{W}}{1\ \text{m}^2\ \text{earth surface}}$$

Solar energy reflected, averaged over whole surface area of earth

$$\frac{106\ \text{W}}{1\ \text{m}^2\ \text{earth surface}}$$

Solar energy absorbed by atmosphere and earth, averaged over whole surface area of earth

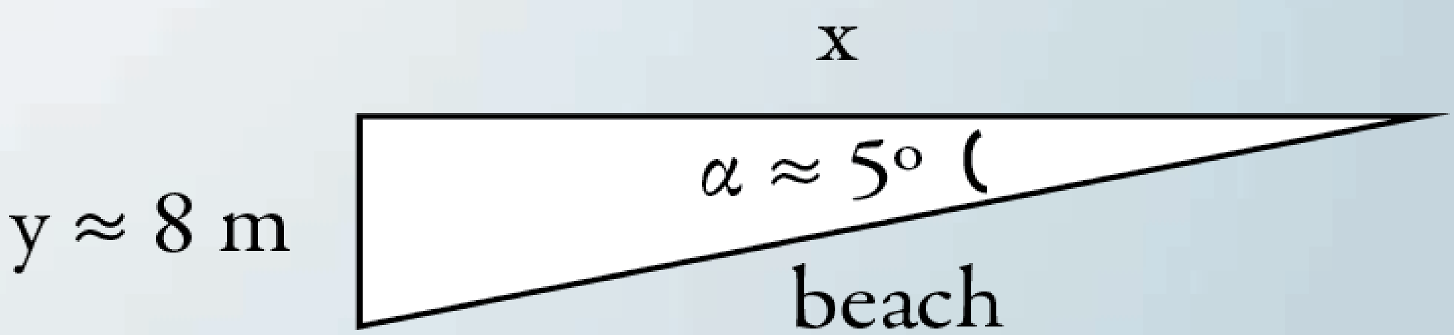
$$\frac{236\ \text{W}}{1\ \text{m}^2\ \text{earth surface}}$$

Solar energy absorbed by Earth's surface, averaged over whole surface area of earth

$$\frac{200\ \text{W}}{1\ \text{m}^2\ \text{earth surface}}$$

Requested Topics

- Trigonometry function of tangent (and question 3 on HW 2) - How to get tangents on calculator?



$$\tan\alpha = \frac{\text{opposite}}{\text{adjacent}} = \frac{y}{x}$$

$$x = \frac{y}{\tan\alpha} = \frac{8\text{ m}}{\tan 5^\circ} = \frac{8\text{ m}}{0.087} \approx 90\text{ m}$$

Requested Topics

- Calculations that involve different ways the ozone levels can be described
  - The **Dobson unit** (DU) is a unit of measurement of the density of a column of a trace gas in the Earth's atmosphere.
  - One Dobson unit refers to a layer of gas that would be 10 μm thick under standard temperature and pressure (273.15 K and 100 kPa).
  - 300 DU of ozone brought down to the surface of the Earth at 0 C° would occupy a layer only 3 mm thick.

Using Dobson Units

Example: Find the moles per cm^2 and molecules per cm^2 in one Dobson Unit of an ideal gas:

$$PV = nRT = P(A \cdot h)$$

$$\frac{n}{A} = \frac{Ph}{RT} = \frac{100\ \cancel{\text{kPa}}\ (10\ \cancel{\mu\text{m}})}{8.314\ \frac{\cancel{\text{L}}\cdot\cancel{\text{atm}}}{\cancel{\text{K}}\cdot\text{mol}}\ 273.15\ \cancel{\text{K}}} \left(\frac{10^3\ \cancel{\text{L}}}{1\ \cancel{\text{m}^3}}\right)\left(\frac{1\ \cancel{\text{m}}}{10^2\ \text{cm}}\right)^3\left(\frac{1\ \cancel{\text{m}}}{10^6\ \cancel{\mu\text{m}}}\right)\left(\frac{10^2\ \cancel{\text{cm}}}{1\ \cancel{\text{m}}}\right)$$

$$= \mathbf{4.403 \times 10^{-8}\ mol/cm^2}\left(\frac{6.022 \times 10^{23}\ \text{molecules}}{1\ \text{mol}}\right) = \mathbf{2.652 \times 10^{16}\ molecules/cm^2}$$

Ozone Concentrations

The peak concentration of ozone in the stratosphere (25 km) is about $5{\times}10^{12}$ molecules/cm^3. Convert this into micrograms ozone per cubic meter.

$$\frac{?\ \mu\text{g}}{\text{m}^3} = \frac{5 \times 10^{12}\ \cancel{\text{molecules}}}{\cancel{\text{cm}^3}} \left(\frac{10^2\ \cancel{\text{cm}}}{1\ \text{m}}\right)^3 \left(\frac{1\ \cancel{\text{mol O}_3}}{6.022 \times 10^{23}\ \cancel{\text{molecules}}}\right)\left(\frac{47.9982\ \cancel{\text{g}}\ \text{O}_3}{1\ \cancel{\text{mol O}_3}}\right)\left(\frac{10^6\ \mu\text{g}}{1\ \cancel{\text{g}}}\right)$$

$$\approx \mathbf{400\ \mu g/m^3}$$

Requested Topics

- Use of Avogadro's number
  - Provides conversion factor that converts between moles of anything and the actual number of individual components, e.g. between moles of an element and actual number of atoms of that element or between moles a molecular compound and number of molecules.

$$\left(\frac{6.022 \times 10^{23} \text{ atoms of element}}{1 \text{ mol element}}\right) \qquad \left(\frac{6.022 \times 10^{23} \text{ atoms Cu}}{1 \text{ mol Cu}}\right)$$

$$\left(\frac{6.022 \times 10^{23} \text{ molecules of molecular compound}}{1 \text{ mol molecular compound}}\right) \qquad \left(\frac{6.022 \times 10^{23}\ H_2O \text{ molecules}}{1 \text{ mol molecular compound}}\right)$$

$$\left(\frac{6.022 \times 10^{23} \text{ formula units of ionic compound}}{1 \text{ mol ionic compound}}\right) \qquad \left(\frac{6.022 \times 10^{23}\ Na_2CO_3}{1 \text{ mol } Na_2CO_3}\right)$$

$$\left(\frac{6.022 \times 10^{23} \text{ ions}}{1 \text{ mol ion}}\right) \qquad \left(\frac{6.022 \times 10^{23}\ {CO_3}^{2-}}{1 \text{ mol } {CO_3}^{2-}}\right)$$

Ozone Concentrations

The global average ozone column density is about 7×10^{18} molecules/cm^2. Convert this into Dobson units.

$$? \, \text{DU} = \frac{7 \times 10^{18} \, \cancel{\text{molecules}}}{\cancel{\text{cm}^2}} \left(\frac{\cancel{\text{cm}^2} \cdot \text{DU}}{2.652 \times 10^{16} \, \cancel{\text{molecules}}} \right) = 264 \, \text{DU} \approx \mathbf{300 \, DU}$$

Requested Topics

- Question 49 (qualitative topics) - how detailed do we need to be?...**what's found on PowerPoint slides.**
  - For the carbon, nitrogen, sulfur, and phosphorus biogeochemical cycles, answer the following questions.
    - What is the **importance** of the cycle to life?
    - What different **chemical forms** (species) are involved?
    - What are the main **processes and chemical reactions**?
    - What are the **human impacts** on the cycle?

Requested Topics

- ppm, ppb, how to use them in calculations

$$\text{ppm} = \frac{?\,(\text{unit})\,(\text{part})}{\text{million}\,(\text{unit})\,(\text{whole})} = \frac{\text{---}\,(\text{unit})(\text{part})}{\cancel{(\text{unit})\,\text{whole}}}\left(\frac{10^6\,\cancel{(\text{unit})\,\text{whole}}}{1\,\text{million}\,(\text{unit})\,\text{whole}}\right)$$

$$\frac{?\,(\text{unit})\,(\text{part})}{(\text{unit})\,(\text{whole})} = \frac{(\text{ppm})\,(\text{unit})(\text{part})}{\cancel{\text{million}\,(\text{unit})\,\text{whole}}}\left(\frac{1\,\cancel{\text{million}\,(\text{unit})\,\text{whole}}}{10^6\,(\text{unit})\,\text{whole}}\right)$$

Stock/Flow Problems

- Steady State ($F_{in} = F_{out}$)

  $S(t) = S_0 \quad F = S/t$

- $\Delta F = F_{in} - F_{out}$ = constant (+ or -)

  $S(t) = S_0 + \Delta F t$

- Exponential Growth of Stocks

  $S(t) = S_0 e^{rt}$

- Exponential decline (decay) of Stocks

  $S(t) = S_0 e^{-rt}$

- Exponential increase in outflow

  $$S(t) = S_0 - \frac{F_0}{r}(e^{rt} - 1)$$

Requested Topics

- 17. Calculations using the coefficients in a balanced equation: How do we know all will be used without knowing the limiting reactant?
  - If amount of one reactant given, assume it’s limiting.
  - If amounts of two reactants given, calculate amount of product from each amount of reactant. The reactant that yields the least product is the limiting reactant.
  - Otherwise, assume stoichiometric amounts.

Requested Topics

- 22. Calculations with Planck's constant…converting between wavelength and energy. How does wavelength affect the energy? How can we find the energy of the photon without using both frequency and wavelength?

$$\varepsilon = h\nu$$

$$c = \lambda\nu$$

$$\nu = \frac{c}{\lambda}$$

$$\varepsilon = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{\varepsilon}$$

ε = energy of photon

h = Planck's constant = 6.626×10^{-34} J•s

c = velocity of light = 2.9979×10^{8} m/s

ν = frequency

λ = wavelength

Gross Primary Production, GPP

- Autotrophs

  $CO_2 + H_2O \rightarrow$ organic molecules, e.g. $C_6H_{12}O_6$

  Radiant energy $\rightarrow$ chemical potential energy
- Energy stored in organic molecules supplies energy needs of both autotrophs and heterotrophs.
- The total rate of formation of these substances (amount per time) is called the gross primary production, GPP.
- Because there are lots of different organic molecules, the rate of formation of these molecules can be described in terms of the mass of carbon in the substances formed per time, e.g. Gt(C)/y.

Net Primary Production, NPP

- The autotrophs convert some of the organic molecules that are part of the GPP back into CO_2 and H_2O in plant respiration to provide energy to run the autotroph (plant respiration).

- The portion that remains is available for autotroph growth and for the energy needs of heterotrophs. This is the net primary production, NPP, which is the difference between the rate at which the plants in an ecosystem produce useful chemical energy (GPP) and the rate at which they use some of that energy during autotroph respiration.

  NPP = GPP - respiration [by plants]

- Both gross and net primary production can be expressed in units of mass/area/time, e.g. Gt(C)/m^2/y, or mass/time, Gt(C)/y.

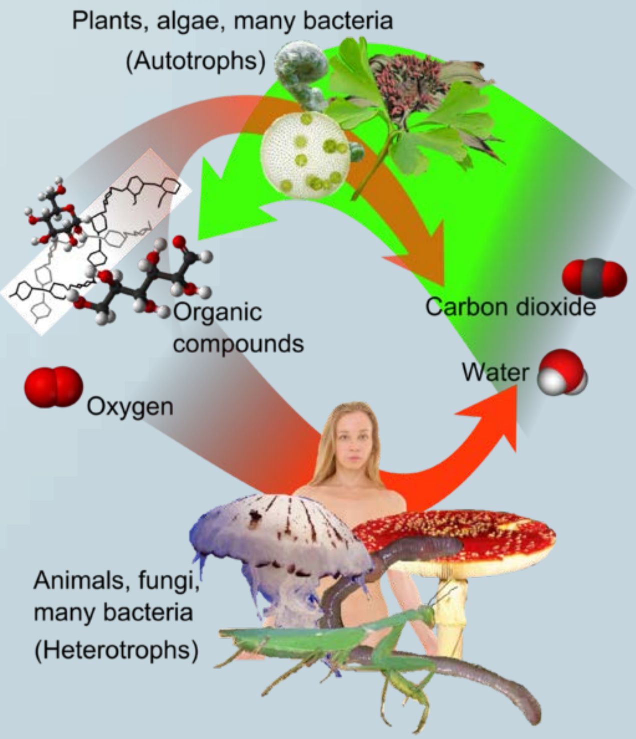
GPP and NPP

CO_2 + H_2O + radiant energy $\rightarrow$ higher energy organic molecules, e.g. $C_6H_{12}O_6$ $\rightarrow$ GPP

GPP = NPP + autotroph respiration (R)

rate at which
higher energy organic molecules, e.g. $C_6H_{12}O_6$ $\rightarrow$ CO_2 + H_2O + energy

Rate of formation of more complex molecules that are available to provide energy for autotroph growth and heterotroph growth and respiration



Conversion of Solar Energy to Biomass

Simplified photosynthesis:

$$CO_2 + H_2O + \text{energy} \rightarrow CH_2O + O_2$$

(Actual typical photosynthate: $C_{1480}H_{2960}O_{1480}N_{160}P_{18}S_{10}$)

Simplified respiration or combustion:

$$CH_2O + O_2 \rightarrow CO_2 + H_2O + \text{energy}$$

"Fixing" 1 g of organic C requires about 40 kJ of energy.

"Burning" 1 g of organic C releases about 40 kJ of energy.

Problems that deal with net primary productivity

- Global GPP ≈ 200 Gt C/y (± large uncertainty)
- Global NPP ≈ 100 Gt C/y ± 25 Gt C/y
  - Estimate has gone up since Cow published: 75 → 100
- Terrestrial NPP ≈ 60 Gt C/y
  - Varies widely by biome type; see *Cow* Appendix XII (old estimates)
- Ocean NPP ≈ 50 Gt C/y ± 10 Gt C/y (hard to measure)

Problem:

- Calculate the joules of energy per year derived from the NPP of 100 Gt C/yr.

$$\frac{?\,\mathrm{J}}{1\ \mathrm{yr}} = \frac{100\ \cancel{\mathrm{Gt}}\ \cancel{\mathrm{C}}}{1\ \cancel{\mathrm{yr}}}\left(\frac{10^9\ \cancel{\mathrm{t}}}{1\ \cancel{\mathrm{Gt}}}\right)\left(\frac{10^6\ \cancel{\mathrm{g}}}{1\ \cancel{\mathrm{t}}}\right)\left(\frac{40\ \cancel{\mathrm{kJ}}}{1\ \cancel{\mathrm{g}}\ \cancel{\mathrm{C}}}\right)\left(\frac{10^3\ \cancel{\mathrm{J}}}{1\ \cancel{\mathrm{kJ}}}\right) \approx \mathbf{4.0 \times 10^{21}\ J/yr}$$

NPP Percentage of Total Solar Radiation

- Calculate the power in TW derived from 100 Gt C/yr. What percentage of the total solar radiation (100,000 TW) is this?

$$? \text{ TW} = \frac{100 \cancel{\text{Gt}}\ \cancel{\text{C}}}{1 \cancel{\text{yr}}}\left(\frac{10^9 \cancel{\text{t}}}{1 \cancel{\text{Gt}}}\right)\left(\frac{10^6 \cancel{\text{g}}}{1 \cancel{\text{t}}}\right)\left(\frac{40 \cancel{\text{kJ}}}{1 \cancel{\text{g}}\ \cancel{\text{C}}}\right)\left(\frac{10^3 \cancel{\text{J}}}{1 \cancel{\text{kJ}}}\right)\left(\frac{1 \cancel{\text{W}} \bullet \cancel{\text{s}}}{1 \cancel{\text{J}}}\right)\left(\frac{1 \text{ TW}}{10^{12} \cancel{\text{W}}}\right)$$

$$\left(\frac{1 \cancel{\text{yr}}}{365 \cancel{\text{day}}}\right)\left(\frac{1 \cancel{\text{day}}}{24 \cancel{\text{hr}}}\right)\left(\frac{1 \cancel{\text{hr}}}{60 \cancel{\text{min}}}\right)\left(\frac{1 \cancel{\text{min}}}{60 \cancel{\text{s}}}\right) \approx \mathbf{130 \text{ TW}}$$

$$\frac{? \text{ TW NPP}}{\text{TW solar}} \times 100 = \frac{130 \text{ TW NPP}}{100{,}000 \text{ TW solar}} \times 100 = \mathbf{0.13\%}$$

Problems that deal with net primary productivity

- See COW page 257 for NPPs for different biomes, e.g. 0.29 kg(C)/m^2/y for cultivated land.

Problem:

- Calculate the gigajoules of energy per month derived from the NPP of 100 acres of cultivated land.

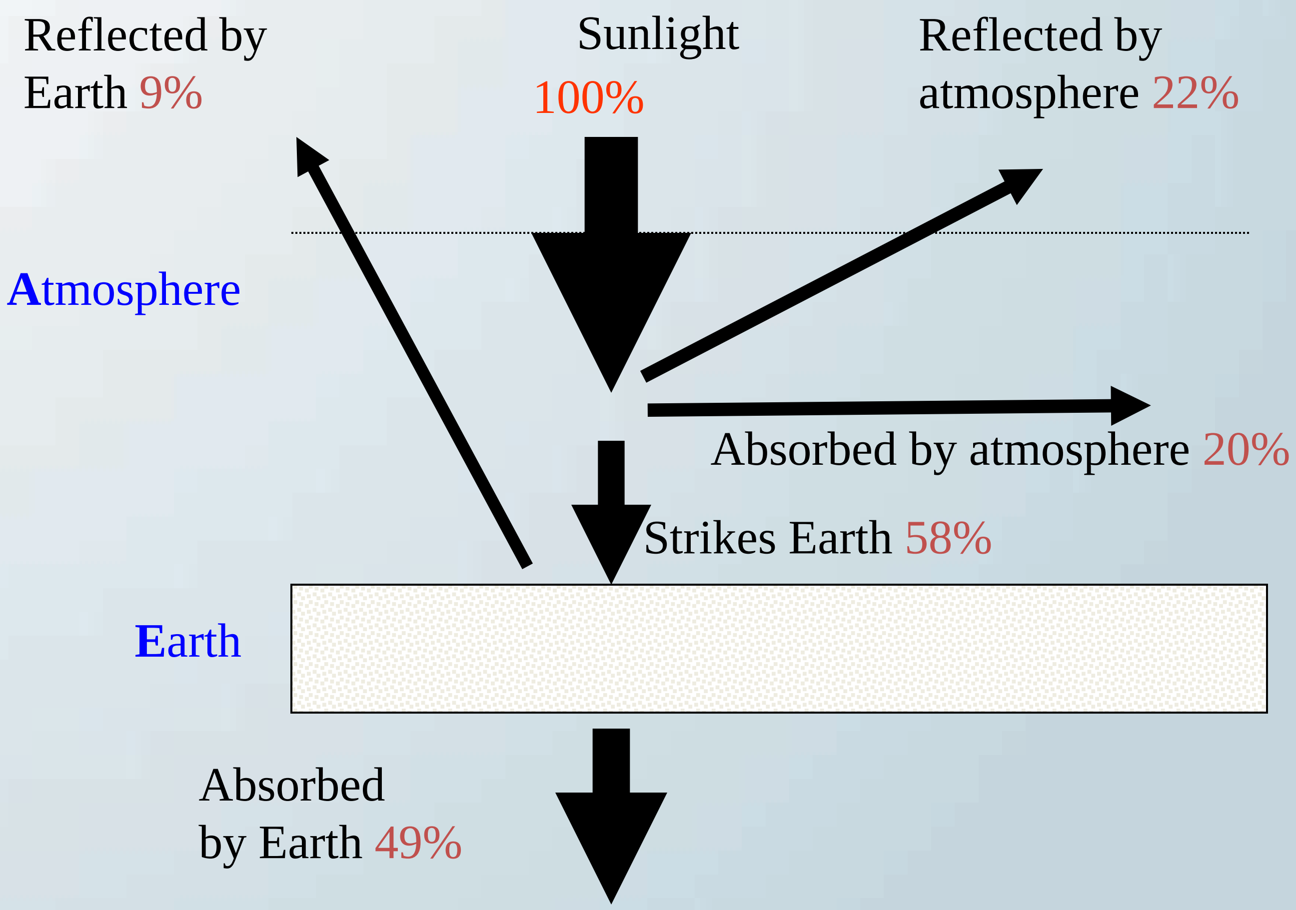
$$\frac{?\ \text{GJ}}{\text{month}} = 100\ \cancel{\text{acre}}\left(\frac{4047\ \cancel{\text{m}^2}}{1\ \cancel{\text{acre}}}\right)\left(\frac{0.29\ \cancel{\text{kg}(\text{C})}}{\cancel{\text{m}^2}\cdot\cancel{\text{y}}}\right)\left(\frac{10^3\ \cancel{\text{g}}}{1\ \cancel{\text{kg}}}\right)\left(\frac{40\ \cancel{\text{kJ}}}{1\ \cancel{\text{g}(\text{C})}}\right)\left(\frac{1\ \text{GJ}}{10^6\ \cancel{\text{kJ}}}\right)\left(\frac{1\ \cancel{\text{y}}}{12\ \text{month}}\right)$$

$$\approx \mathbf{3.9 \times 10^2\ GJ/month}$$

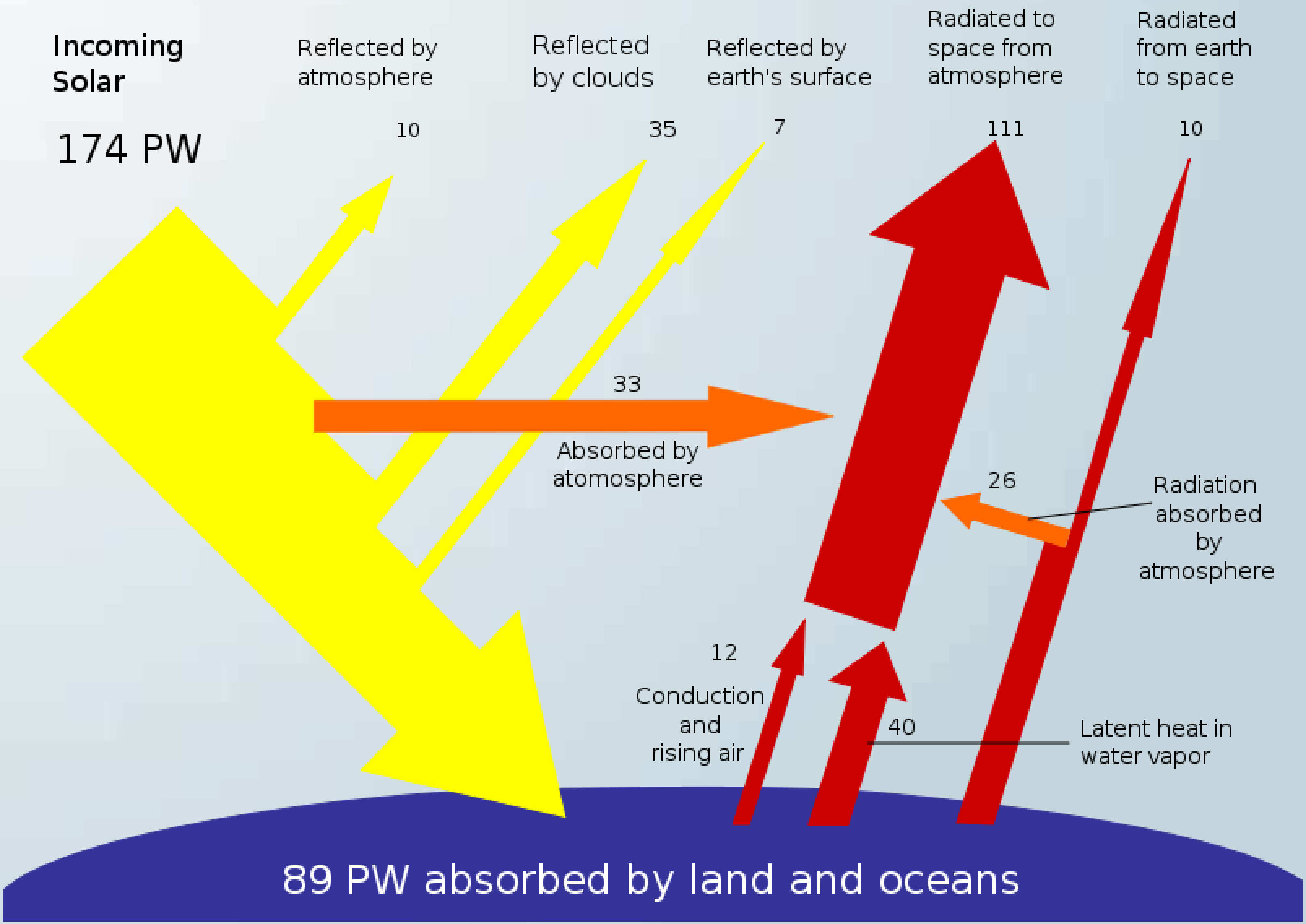
Requested Topics

- #15 (Describe what happens to the solar energy that reaches the surface of the Earth)

Fate of Incoming Solar (short-wave) Radiation Striking Top of Atmosphere

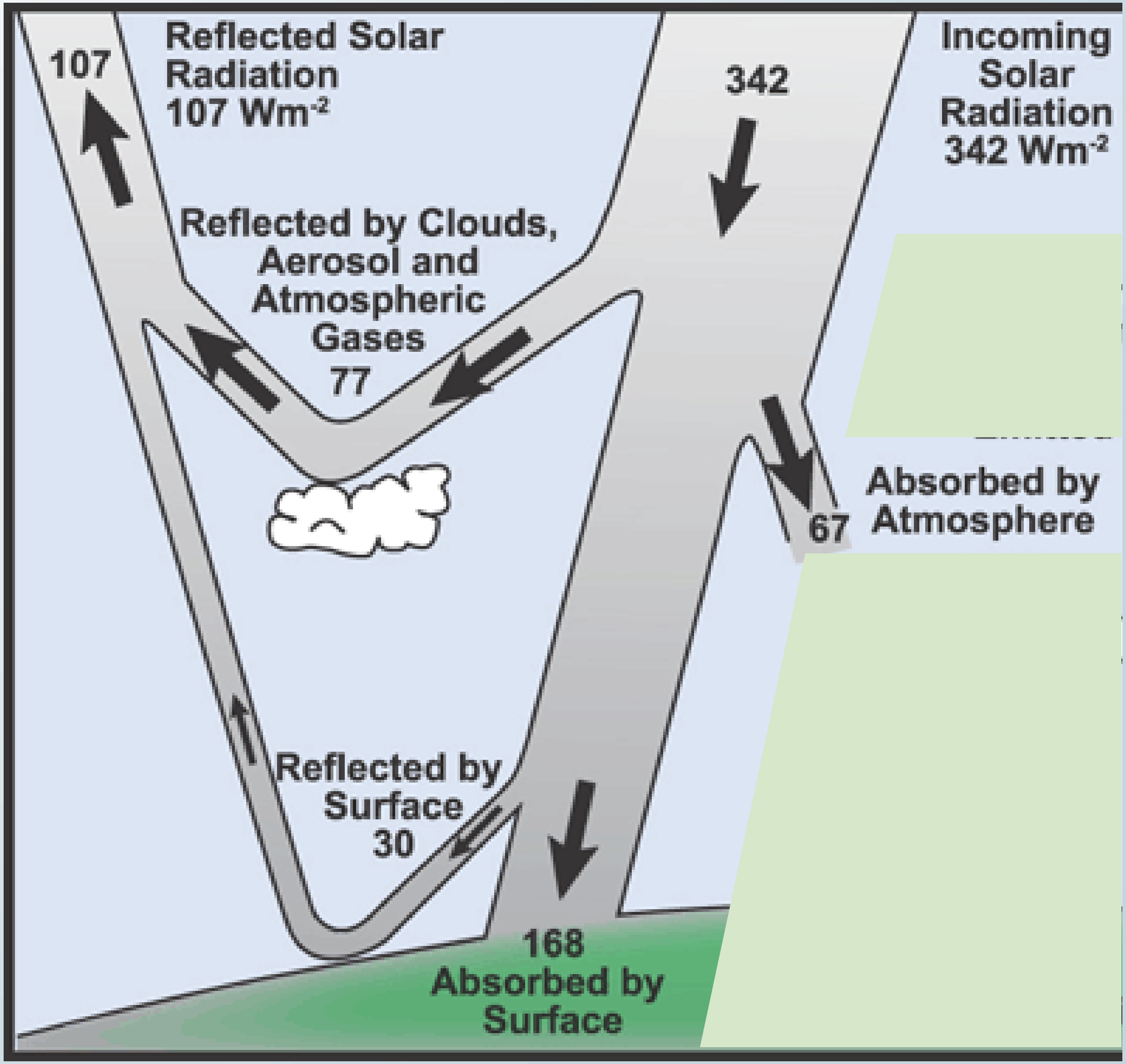


Fate of Incoming Solar Energy.

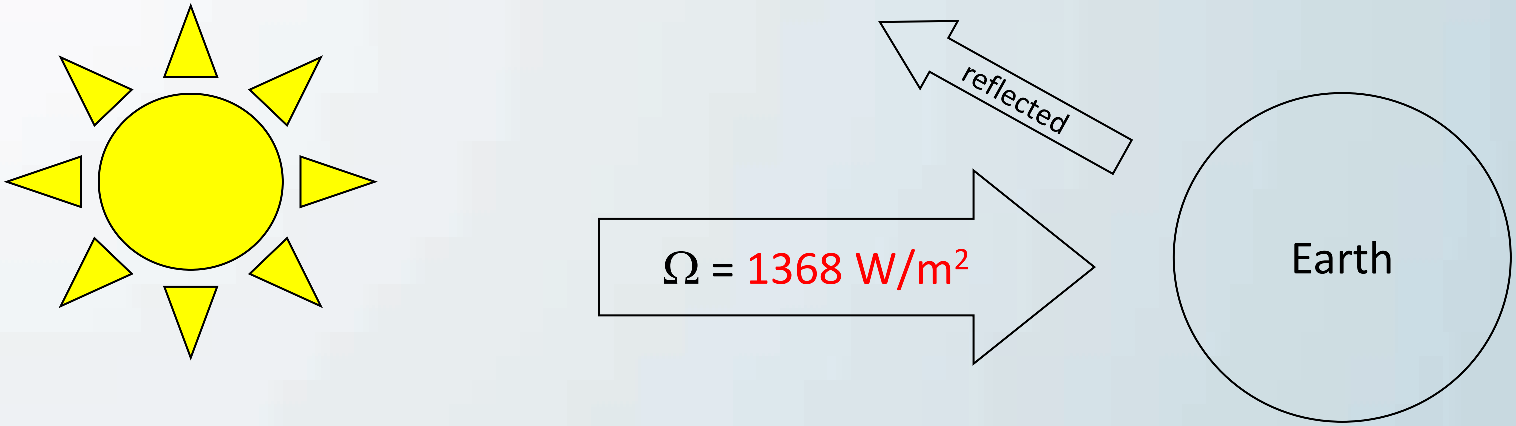


Fate of Incoming Solar Radiation

In W/m²



Solar Summary



Solar energy intercepted by earth = 174,000 TW

Solar energy intercepted per m^2 Earth = 342 W/m^2

Earth's albedo α (reflectivity) = 0.31 (portion of sunlight reflected back to space)

Solar energy absorbed in atmosphere + surface

$= (1 - 0.31) \times 342$ W/m^2 = 235 W/m^2

Solar energy striking surface ≈ *200 W/m^2*

averaged over all latitudes and all seasons

Requested Topics

- #16 (Describe how the greenhouse effect traps energy radiated from the Earth's surface)
  - As the Earth cools, it emits infrared (IR) photons.
  - When a greenhouse gas molecule absorbs an IR photon, the molecule gets excited to a higher vibrational energy.
  - When the molecule returns to a more stable vibrational energy, it emits an IR photon in a random direction.
  - Some of the remitted photons return to Earth.

Requested Topics

- #16 (Describe how the greenhouse effect traps energy radiated from the Earth's surface)

NATURALLY MODERATED GREENHOUSE EFFECT

ANTHROPOGENIC GREENHOUSE EFFECT - ADDING GHG' S, INCREASING RADIATIVE FORCING

GHG Atmospheric Lifetimes and Global Warming Potential

- Each GHG has its own atmospheric residence time, governed by the sinks that remove it from the atmosphere.
- The global warming potential (GWP) of each GHG is measured relative to CO_2. GWP combines the GHG's efficiency at trapping IR radiation with its residence time in the atmosphere.
- Example: Over a 100 year period, a molecule of CH_4 contributes as much radiative forcing as 25 molecules of CO_2.

Global Warming Potential (GWP) = radiative impact of a GHG per molecule relative to impact of CO_2, taking into account its radiative properties and atmospheric lifetime

Atmospheric lifetime and GWP relative to CO_2 at different time horizon for various greenhouse gases.

Gas name	Chemical formula	Lifetime (years)	Global warming potential (GWP) for given time horizon		
			20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See above	1	1	1
Methane	CH_4	12	72	25	7.6
Nitrous oxide	N_2O	114	289	298	153
CFC-12	CCl_2F_2	100	11,000	10,900	5 200
HCFC-22	$CHClF_2$	12	5160	1810	549
Tetrafluoromethane	CF_4	50,000	5210	7390	11,200
Hexafluoroethane	C_2F_6	10,000	8630	12,200	18,200
Sulphur hexafluoride	SF_6	3200	16,300	22,800	32,600
Nitrogen trifluoride	NF_3	740	12,300	17,200	20,700

Requested Topics

- What’s GWP of CO_2…**1**

Requested Topics

- Percentages as conversion factors
- Percentage can be used as unit analysis conversion factors to convert between units of the part and units of the whole.

For X% $\dfrac{\text{X (any unit) part}}{\text{100 (same unit) whole}}$

For X% by mass $\dfrac{\text{X (any mass unit) part}}{\text{100 (same mass unit) whole}}$

For X% by volume $\dfrac{\text{X (any volume unit) part}}{\text{100 (same volume unit) whole}}$

Requested Topics

- Use molar volume to convert between volume of gas and moles of gas

Standard Temperature and Pressure

- **Standard Temperature and Pressure (STP)** = the standard sets of conditions for experimental measurements established to allow comparisons to be made between different sets of data. (There are no universally accepted standards.)
  - International Union of Pure and Applied Chemistry (IUPAC) uses 273.15 K (0 °C, 32 °F) and 100 kPa (14.504 psi, 0.986 atm, 1 bar)
  - An unofficial, but commonly used standard is **standard ambient temperature and pressure** (**SATP**) of 298.15 K (25 °C, 77 °F) and 100 kPa (14.504 psi, 0.986 atm). This is the most useful set of values for us.
  - National Institute of Standards and Technology (NIST) uses 20 °C (293.15 K, 68 °F) and 101.325 kPa (14.696 psi, 1 atm)

Molar Volume at STP

- You will find the following derived conversion factor useful for converting between volume and moles of gas.

$$PV = nRT$$

$$\frac{V}{n} = \frac{RT}{P} = \frac{\left(\frac{8.3145\ \mathrm{L} \cdot \cancel{\mathrm{kPa}}}{\cancel{\mathrm{K}} \cdot \mathrm{mol}}\right)(298.15\ \cancel{\mathrm{K}})}{100\ \cancel{\mathrm{kPa}}} = \left(\frac{24.790\ \mathrm{L}}{1\ \mathrm{mol}}\right)_{\mathrm{SATP}}$$

Requested Topics

- 8.Given two of the following for a steady state system, calculate the third: stock, flow rate, and time.

  $\text{Flow} = F_{in} = F_{out} = \text{Stock(S)} \div \text{time(t)}$

  Stock (S) constant

  $F = S/T$

Requested Topics

- Problem set 1 # 3: At that rate (5 Gt/y), how many years would it take for all the continents above sea level to wash into the sea?

$$? \text{ yr} = (1.48 \times 10^{14} \cancel{\text{m}^2} \bullet 840 \cancel{\text{m}}) \left(\frac{10^3 \cancel{\text{L}}}{1 \cancel{\text{m}^3}} \right) \left(\frac{2.7 \cancel{\text{kg}}}{1 \cancel{\text{L}}} \right) \left(\frac{1 \cancel{\text{t}}}{10^3 \cancel{\text{kg}}} \right) \left(\frac{1 \cancel{\text{Gt}}}{10^9 \cancel{\text{t}}} \right) \left(\frac{1 \text{ yr}}{5 \cancel{\text{Gt}}} \right)$$

$$= 67132800 \text{ yr} \approx \mathbf{7 \times 10^7 \text{ yr}}$$