RADIATION PHYSICS

① KIRCHOFF'S LAW

- Any body $T > 0$ K radiates energy
- Radiation proportional to absorption

W_i = power density of radiation (power/area)
= energy FLUX (energy/time/area)

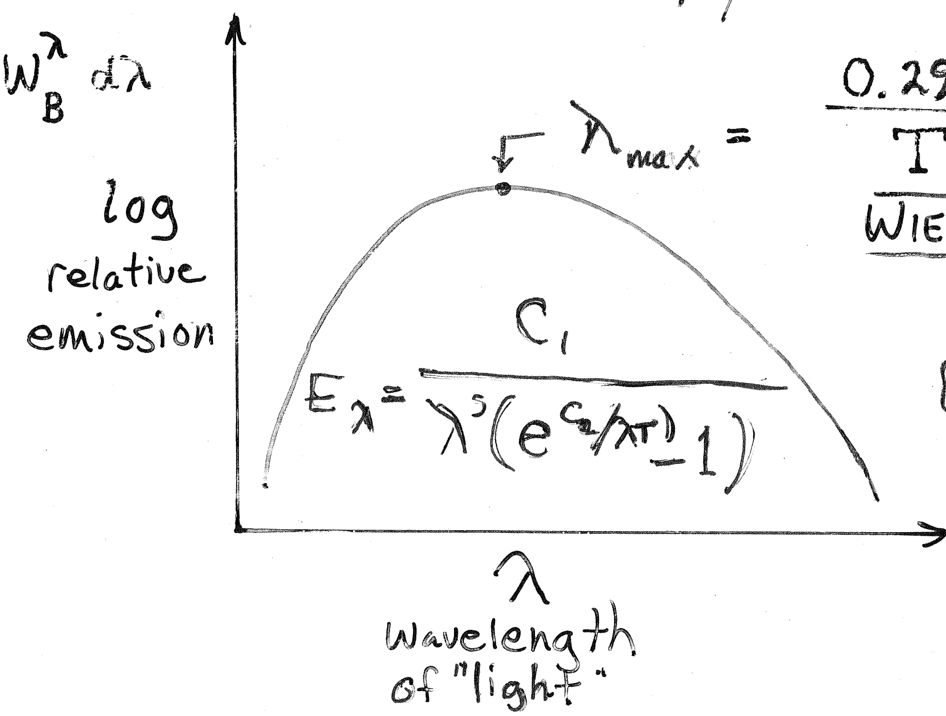
a_i = specific absorptivity $(0 < a_i < 1)$

$$\frac{W_1}{a_1} = \frac{W_2}{a_2} = W_B$$ = black body radiator power density

② PLANCK'S LAW

Radiation from a black body is distributed w/r/t wavelength

$$W_B = \int_0^\infty W_B^\lambda \, d\lambda$$



$$\lambda_{max} = \frac{0.29 \text{ cm-K}}{T}$$

WIEN DISPLACEMENT LAW

$$E_\lambda = \frac{C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)}$$

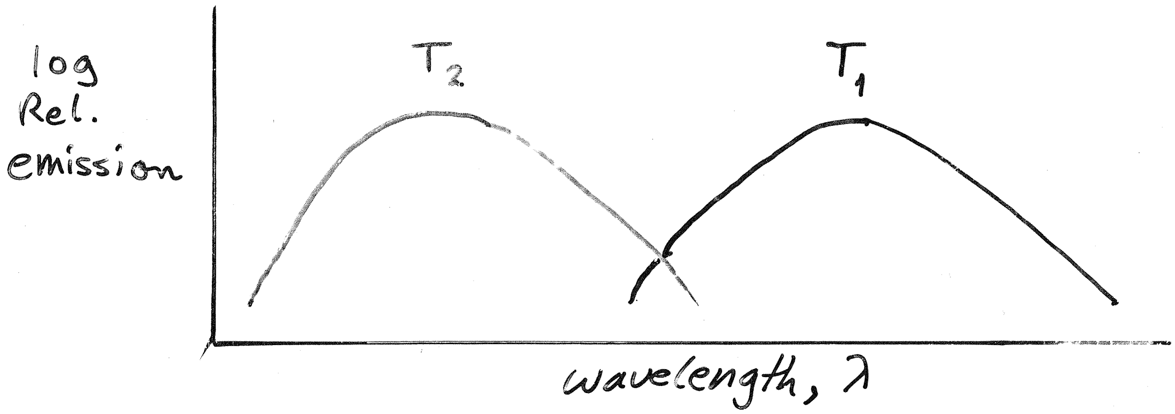
E = total emissive power = $W_B \cdot A$

3

STEFAN-BOLTZMANN LAW

CONSIDER TWO BLACK BODIES

$T_2 \gg T_1$



Which body is radiating more thermal energy?

BLACK BODY:

$$W_B = \sigma T^4$$

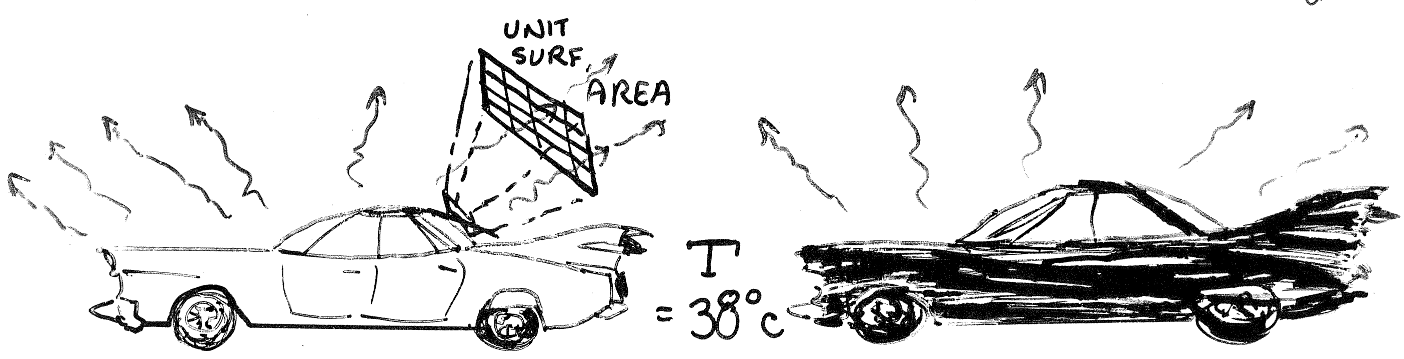
$\sigma = 8.3 \times 10^{-11}$ cal cm^{-2} min^{-1} K^{-4}

$= \underline{5.7} \times 10^{-8}$ J m^{-2} s^{-1} K^{-4}

ANY REAL BODY:

$$W_i = \varepsilon_i \sigma T^4$$

$\varepsilon_i \equiv$ emissivity $= a_i$ at thermal equilibrium



$T = 38°C$

$= 311$ K

$W_1 = (0.3)(8.3E-11)(311)^4$

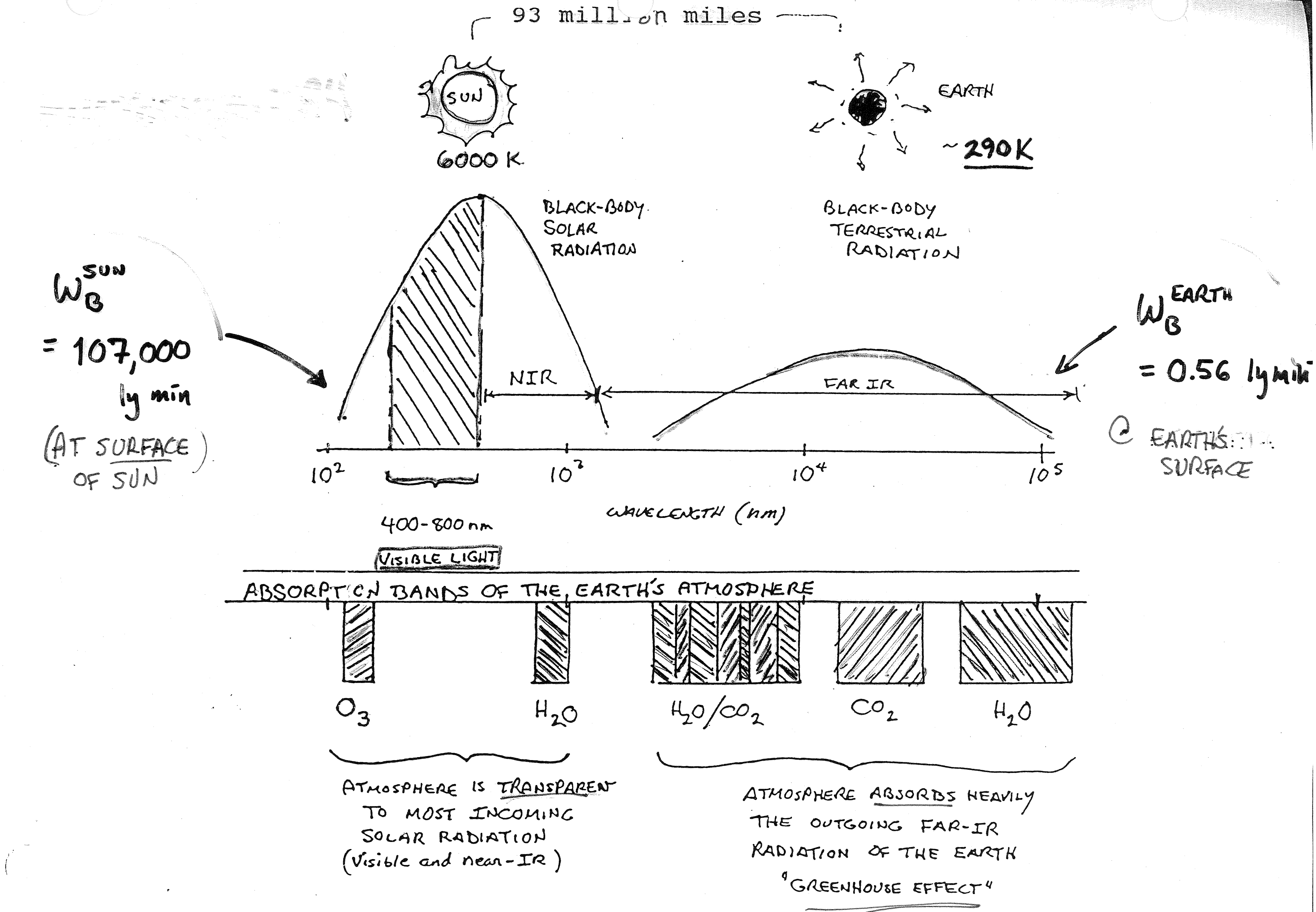
$= 0.23$ cal cm^{-2} min^{-1} $\left(\frac{\text{Langleys}}{\text{min}}\right)$

$= 160$ Watt/m^2

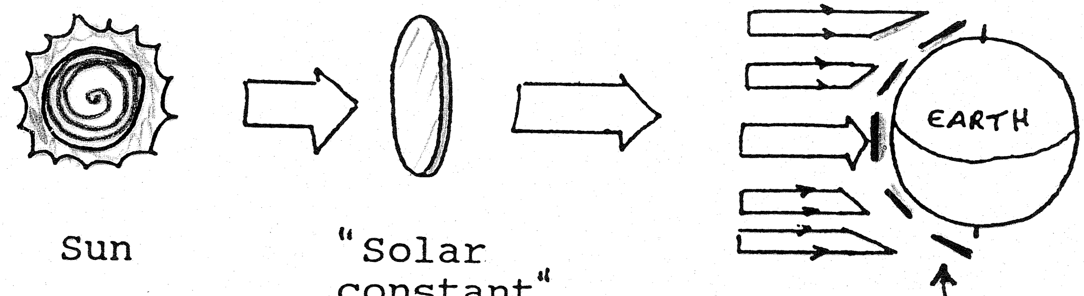
$W_2 = (0.8)(8.3E-11)(311)^4$

$= 0.62$ langleys/min

$= 434$ W/m^2


93 million miles
SUN
6000 K
EARTH
~290K
BLACK-BODY SOLAR RADIATION
BLACK-BODY TERRESTRIAL RADIATION
W_B^{SUN} = 107,000 ly min
(AT SURFACE OF SUN)
W_B^{EARTH} = 0.56 ly min
@ EARTH'S SURFACE
NIR
FAR IR
10^2
10^3
10^4
10^5
WAVELENGTH (nm)
400-800 nm
VISIBLE LIGHT
ABSORPTION BANDS OF THE EARTH'S ATMOSPHERE
O_3
H_2O
H_2O/CO_2
CO_2
H_2O
ATMOSPHERE IS TRANSPAREN TO MOST INCOMING SOLAR RADIATION (Visible and near-IR)
ATMOSPHERE ABSORBS HEAVILY THE OUTGOING FAR-IR RADIATION OF THE EARTH
"GREENHOUSE EFFECT"

The spherical shape of the earth a is very important:



At higher latitudes, light is spread over greater area; hence, less intense.

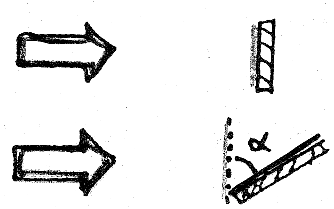
$W_B^0 \approx 2.0$ langleys/min (cal/cm^2/min) $\approx$ 1,400 W/m^2 (IN OUTER SPACE)

< 0.001 % OF W_B AT SURFACE OF SUN

"Insolation" = I_o

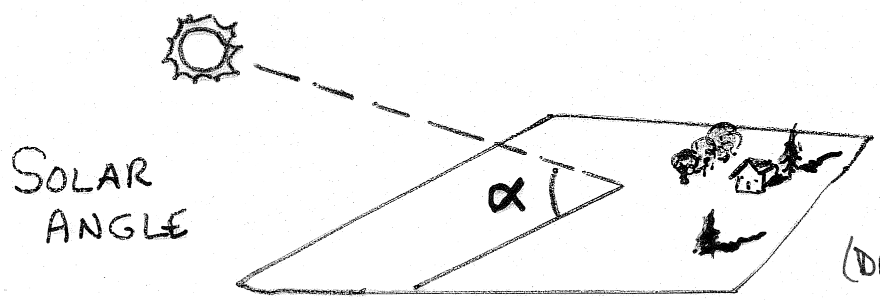
$$I_o = W_{Bo} \sin \alpha$$
$$= W_{Bo} \cos \phi$$
$$\alpha = [90° - (\text{latitude})]$$ for noon at the equinox

$\alpha \equiv$ solar angle (See Eagleson's chapter)



Most intense per unit area of surface

Less intense per unit area of surface



$$\sin \alpha = \sin \delta \sin \Phi + \cos \delta \cos \Phi \cos \tau$$

(DELTA) δ = DECLINATION

(PHI) Φ = LOCAL LATITUDE

(TAU) τ = HOUR ANGLE

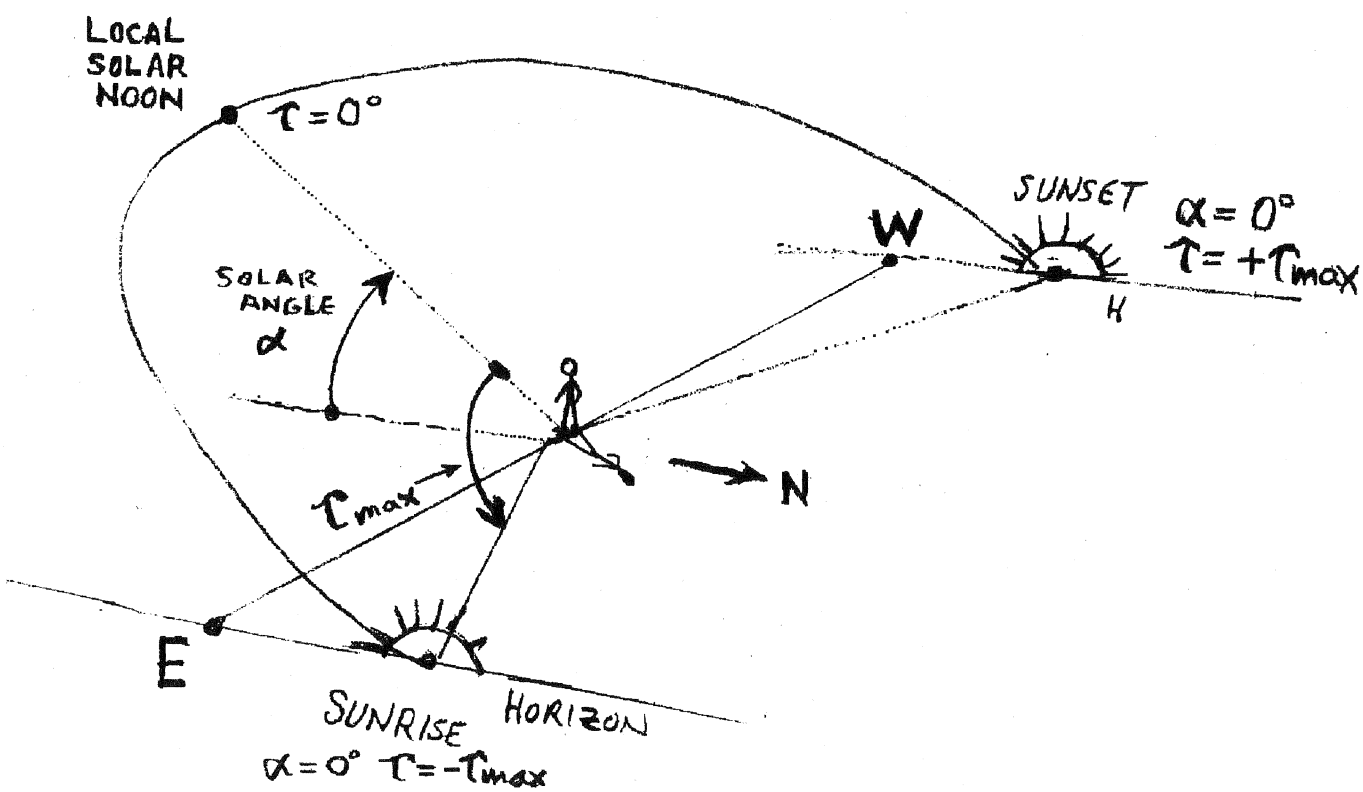
SOLAR ANGLE CALCULATION

$$\sin \alpha = \sin \delta \sin \Phi + \cos \delta \cos \Phi \cos \tau$$

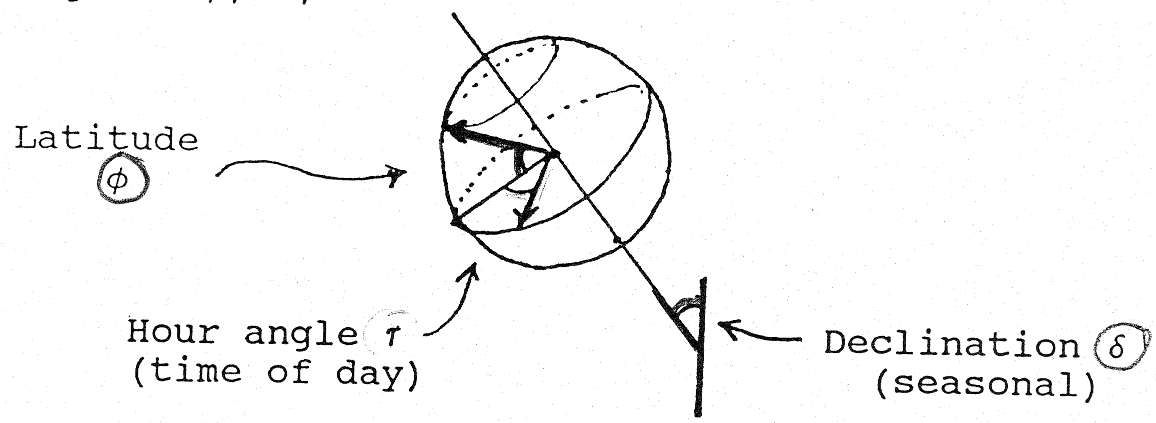
δ = declination
(the seasonally varying angle of the plane traversed by the sun across the sky)

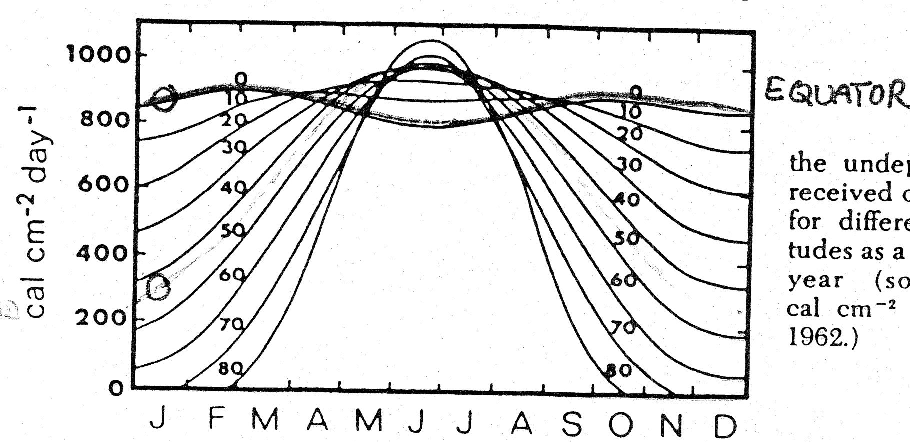
Φ = latitude
(the geographic angle along the surface of the earth)

τ = hour angle of the sun
(the angle of the sun *along* the arc traversed by the sun across the sky)



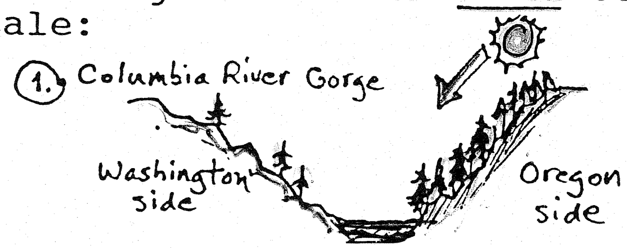
A. Solar angle for a flat surface can be calculated using the three component angles: ϕ, τ, δ.

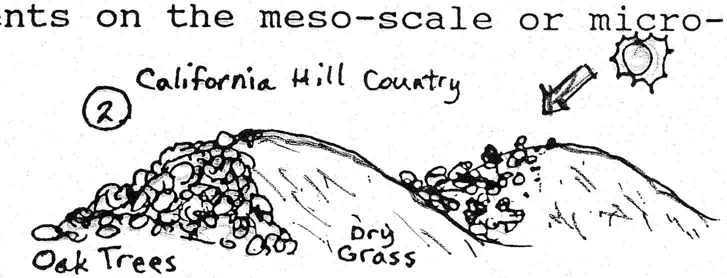




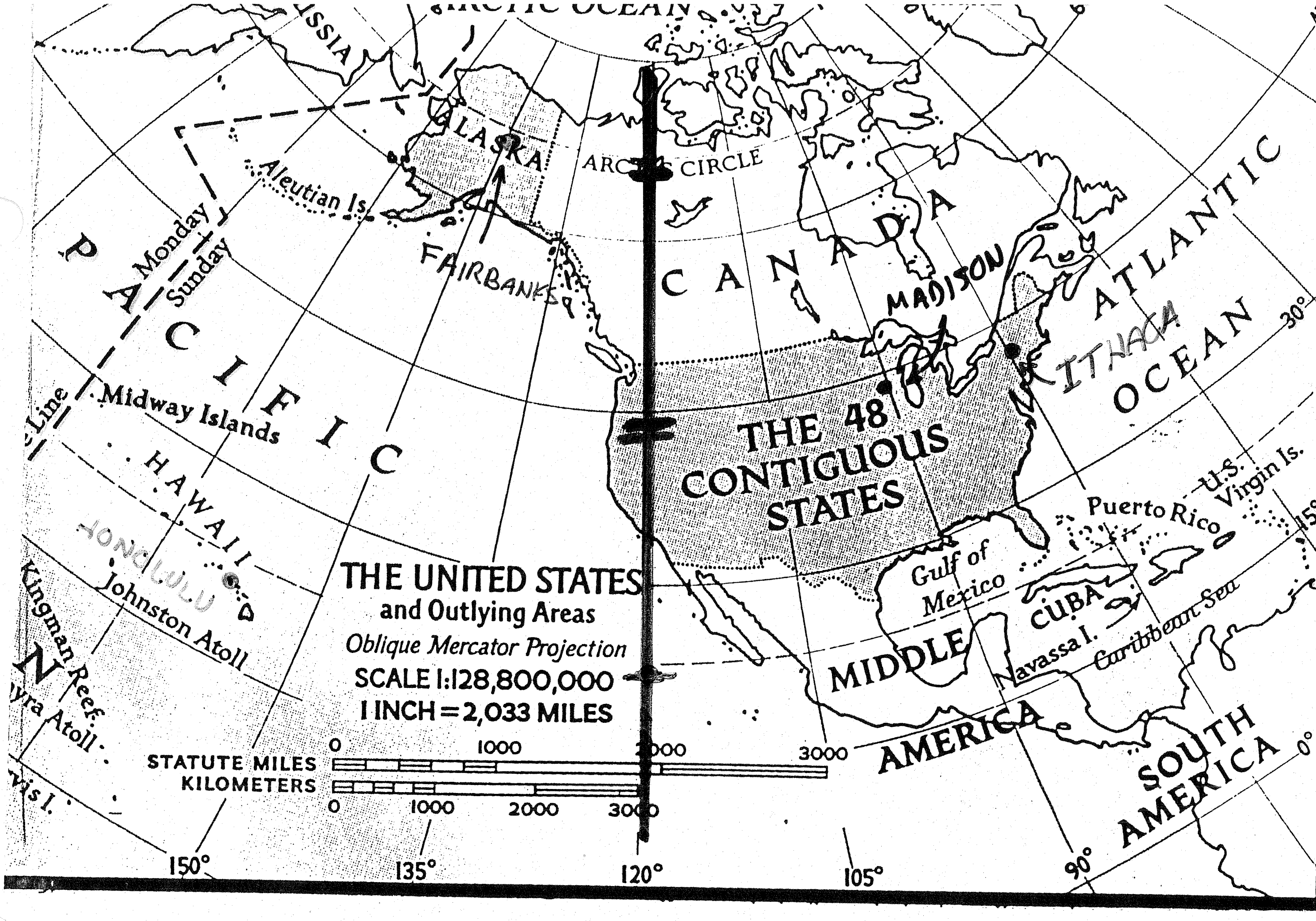
Daily totals of the undepleted solar radiation received on a horizontal surface for different geographical latitudes as a function of the time of year (solar constant 1.94 cal cm^{-2} min^{-1}). (After Gates, 1962.)

B. Solar angle also has <u>local</u> components on the meso-scale or micro-scale:





Absorbance and especially molecular and particulate scattering also affect insolation: smoke, haze, clouds, pollution, etc. So what hits the surface is significantly <u>less</u> than (W_{Bo} sin α).



COMPARATIVE LATITUDES OF FOUR U.S. CITIES

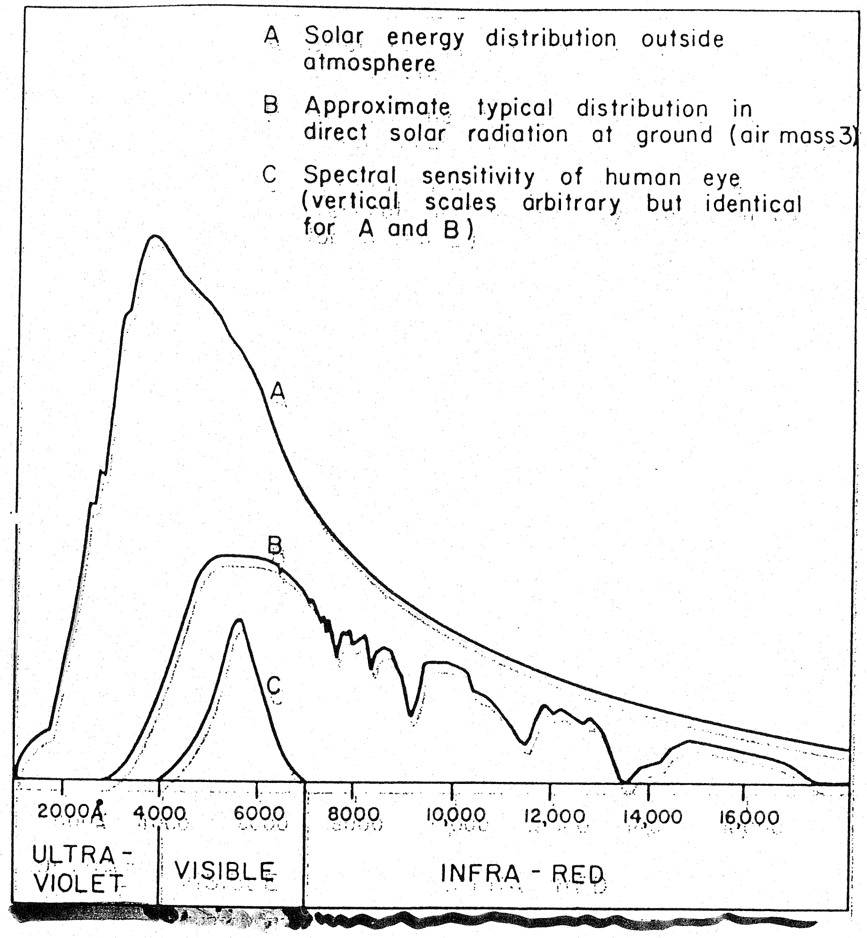


FIGURE 109. Spectral distribution of radiant energy outside the atmosphere and at the earth's surface (air mass 3), with the spectral sensitivity of the human eye.

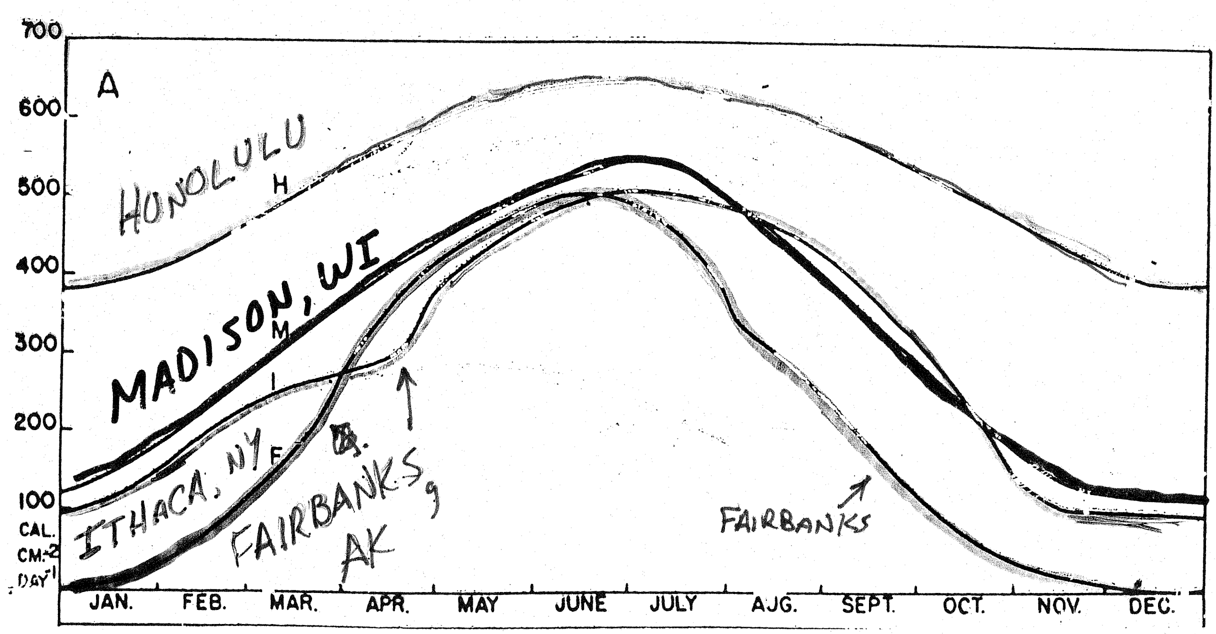


FIGURE 111. *A*, mean radiation (cal. cm.$^{-2}$ day^{-1}) received at various times of year at H, Honolulu, Hawaii, lat. 21°18′ N.; M, Madison, Wisconsin, lat. 43°05′ N.; I, Ithaca, New York, lat. 42°27′ N.; F, Fairbanks, Alaska, lat. 64°52′ N. (after Hand). Note the slightly lower radiation received at nearly all seasons at Ithaca (Lake Cayuga) as compared with Madison (Lake Mendota).

BEER-LAMBERT-BOUGER LAW

INTEGRATE w/r/t DEPTH (z)

$$I_z^{\lambda} = I_0^{\lambda} e^{-a_\lambda z}$$

a_λ = absoption coeff for wavelength λ

OR

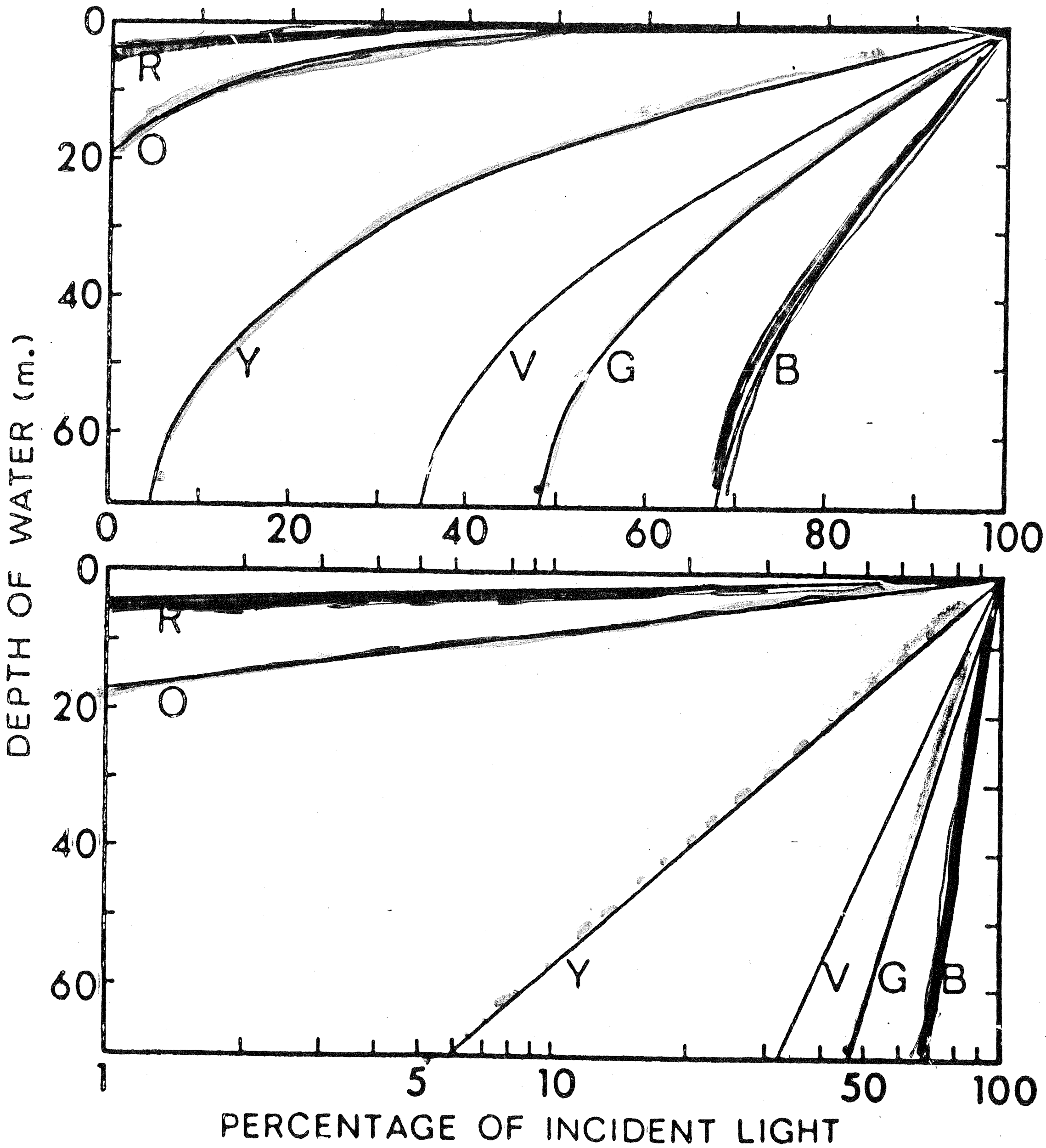
$$\frac{I_z^{\lambda}}{I_0^{\lambda}} = e^{-a_\lambda z}$$

1. LIGHT INTENSITY DROPS OFF EXPONENTIALLY W/ DEPTH (z)

2. EXTENT OF LIGHT ATTENUATION DEPENDS ON WAVELENGTH OF LIGHT

- RED LIGHT: $a_{650\,nm} \rightarrow$ LARGE
- GREEN LIGHT $a_{500} \rightarrow$ MEDIUM
- BLUE LIGHT $a_{450} \rightarrow$ SMALL
- UV LIGHT $a_{300} \rightarrow$ VERY LARGE

"a" also known as the "Extinction Coeff."


DEPTH OF WATER (m.)
0
20
40
60
R
O
Y
V
G
B
0
20
40
60
80
100
0
20
40
60
R
O
Y
V
G
B
1
5
10
50
100
PERCENTAGE OF INCIDENT LIGHT

PRACTICAL APPLICATION

Beer's Law in Natural Water

DEFINE $K \equiv \int_\lambda a_\lambda \, d\lambda$

$K \equiv$ Average absorption of sunlight for natural water

OFTEN MEASURED EMPIRICALLY W/ LIGHT METER

$\beta \equiv$ "EXTRA" absorption often seen in film on surface

$$\frac{I_{SZ}}{I_S^x} = (1-\beta)e^{-Kz}$$

ABSORPTION OF LIGHT BY WATER : Logarithmic Presentation

The exponential equation given by Beer's Law can be linearized by taking the natural log of both sides, or, by plotting light intensity on semi-log scaling.