6.3.5 Scattering of Solar Radiation (p102)

: refraction/ ~~dispersion~~ of light in all direction by particles, but only phase+polarisation may change, not frequency

small particles $D \ll \lambda$ Rayleigh: scattering $\propto 1/\lambda^4$

→ blue sky

why do sun set/rise appear red?

aerosols $D \sim \lambda$ Mie : scattering $\propto 1/\lambda$

more diffuse reflection

How would the sky look during the day if there were no particles in the atmosphere?

direct only : black sky

diffusively : white sky

6.3.6 Clouds

thin stratus , albedo ≈ 0.3

thick stratus , albedo ≈ 0.7

visible : multiple scattering inside clouds

IR : absorption by droplet of water, ice crystals , and water vapor for infrared (strong absorbers of terrestrial radiation)

6.3.7 Solar Radiation at the earth's surface

surface albedo $= \dfrac{\text{reflected}}{\text{incoming}}$ radiation $\approx$

0.20	grass
0.10	forest
0.90	snow
0.05	water
0.30	thin stratus clouds
0.70	thick stratus clouds

albedo is a strong function of wavelength ⟶ vegetation photosynthesis

but biology a small player in energy balance

6.4 Terrestial Radiation (thermal radiation, infrared)

(p 104)

incoming short-wave solar radiation
absorbed @ surface ⟶ surface heating ⟶ $\int_0^\infty \text{Plank}\, d\lambda \propto T^4$
Stefan Boltzmann

⟶ outgoing long-wave terrestrial radiation

↓

all exchange of energy between earth + space via

Radiative Tranfer

real (grey) bodies emit and absorb less radiation than black bodies

absorptivity $a(\lambda) < 1$
emissivity $\varepsilon(\lambda) < 1$

$$\text{emissivity} \quad \varepsilon(\lambda) = \frac{J(\lambda)}{B(\lambda)} = \frac{\text{emitted}}{\text{Planck}} \approx \begin{cases} \text{constant} & \text{solid + fluids} \\ \text{strong } \lambda \text{ dependence} & \text{gases} \end{cases}$$

0.96 water
0.98 vegetation
0.92 land

chromatography

6.4.2 gas ~~chromatopography~~ → discontinueous absorption specta at

$$\Delta E = \hbar \cdot f$$

6.4.3

O_2, N_2 (no dipole moment) ↓ ~~[illegible]~~ electrons jump orbits representing different energy states
↓ high energy ↓ ~~small~~ high frequency ↓ low wavelength

⟹ ultraviolet + visible absorption/emission

H_2O
CO_2 (dipole moment) rotational and relative vibrational modes of energy state change
O_3

↓ lower energy ↓ lower frequency ↓ higher wavelength

⟹ infrared and microwave absorption/emission

→ discrete spetral lines of absorption and emission

6.4.4 but add Doppler shift (moving particles)
add particle-to-particle interactions (collision, kinetic gas theory pressure, temperature)
↓ line broadening, "energy smeared out"

6.5 Radiative Transfer
(p. 110)

Recall: Total Intensity = Absorbed + Reflected + Transmitted Intensity (energy^2)

* *

Recall: Change of Intensity due to absorption + scattering = extinction coefficient intensity density path segment

$$dJ_a = -k \quad J \quad \rho \quad ds$$

Recall: Kirchoff's Law (steady state, no change in temperature)

emissivity = absorptivity

but the emitted energy is dependent on the temperature of the emitting body per Planck's Law

Change of intensity $dJ_e = +k \quad B(T) \quad \rho \quad ds$
due to emission

$B(T)$ Planck

Thus: Total change of intensity along path segment ds *

$$dJ = dJ_a + dJ_e = -k\,\big(J - B(T)\big)\,\rho\,ds$$

or

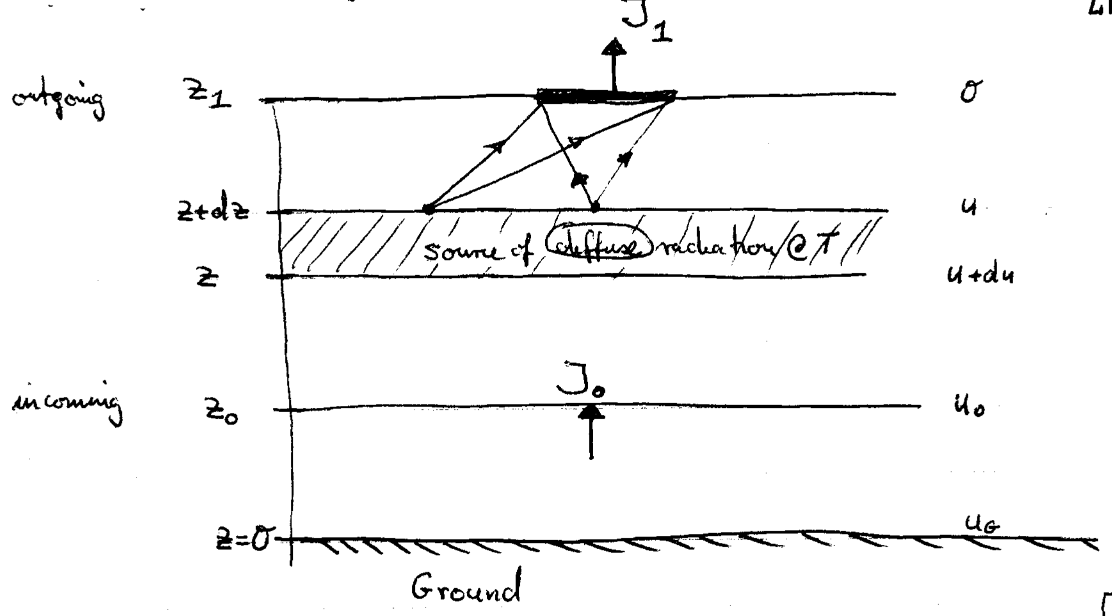
Schwarzchild Radiative Transfer Equation

$$\boxed{\frac{dJ}{dm} = -k\,\big(J - B(T)\big) \quad 2}$$

$dm = \rho \cdot ds \quad \frac{kg}{m^3} \cdot m$

element of mass crossed by radiation

Apply to long-wave outgoing radiation F_{LW} ⑤



$$dJ = \tau \ B(z)\ k\rho\ dz$$

$$\tau \equiv \exp\left[-\int_z^{z_1} k\rho\, dz\right]$$

transmissivity

$$\boxed{\text{or } \frac{dJ}{dz} = B(z)\ \frac{d\tau}{dz}}$$

so $ds = z_1 - z_0$

because $\dfrac{d\tau}{dz} = k\rho \cdot \tau$

$$J_1 - J_0 = \int_{\tau}^{\tau=1} B(z)\, d\tau$$

Recall that optical depth $u = -\int_z^{z_1} k\rho\, dz$ $\qquad \tau = e^u$

or $du = k\rho\, ds$

change variables from $z, dz \xrightarrow{\text{to}} u, du$

$$\frac{dJ}{\cancel{du}} = B(T, u)\ \frac{d\tau(u)}{\cancel{du}} \qquad \Big|\Big| \int$$

$$\int_{J_0}^{J_1} dJ = \int_{\tau(z_0)}^{\tau(z_1)=1} B(u)\, d\tau$$

$\dfrac{d\tau}{du} = \tau$ always

thus $d\tau = \tau\, du$

$$= \int_{u(\tau(z_0))}^{\cancel{u(\tau(z_1))}\,0} B(u)\, \tau\, du$$

$$J_1 - J_0 = \int_{u_0}^{0} B(u)\, e^u\, du$$

Can't do this integral ↯

$$\frac{dJ}{dm} = -k\left(J - B(T)\right) \qquad dm = \rho\, ds$$

Ordinary first order differential equation subject to forcing $B(T)$

$$\frac{dJ}{dm} + kJ = kB(T)$$

Forcing

Find general solution to homogeneous equation (Forcing $= 0$)
Add one particular solution of inhomogeneous equation (Forcing $= kB(T)$)
to get the general solution to the forced problem

↳ $J = J(s, k, B)$ for each wavelength (or frequency)

~~(6.30)~~ then integrate over all wavelength (to get total intensity)

(6.30)

then integrate over a hemisphere (to transform directionality of the diffusive radiation to an upward flux)

(6.32)

Then the total upward infrared radiation becomes

$$\overset{\uparrow}{F}_{LW}(z_1) = \pi B(z_0) + \pi \int_0^{z_1} \tilde{\varepsilon}(z, z_1)\, dB(z)$$

where $\tilde{\varepsilon}(z, z_1) = \underbrace{\sum_i}_{\text{over all wavelength } \lambda_i} a_i^*(z, z_1) \dfrac{dB_i(z)}{dB(z)}$ and $B(z) = \dfrac{\sigma T^4(z)}{\pi}$

absorptivity $a_i^* = 1 - \tau_i^*$

$\tau_i^* =$ diffusive transmissivity