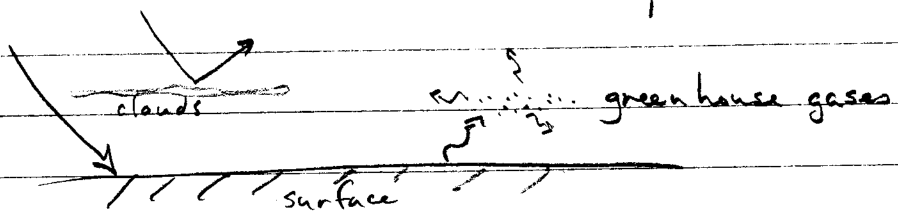
1. The surfaces of the moon and Mercury are ancient. They show a high density of craters from the epoch of heavy bombardment early in the history of the solar system. There has been little resurfacing activity since then, and what has happened seems to have stopped long ago (e.g., the maria on the moon).

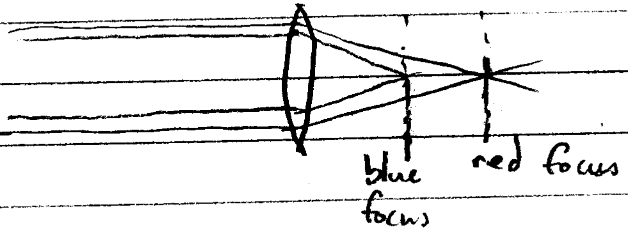
2. Terrestrial temperature is governed by the balance of energy received from the sun and re-radiated into space.



Some sunlight is reflected back into space immediately and does not contribute to heating (the Earth's albedo). The rest is absorbed and heats the surface. →

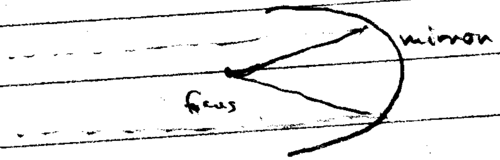
2. (con.) The warm surface re-radiates in the infra-red portion of the spectrum. Greenhouse gases (e.g. H_2O, CO_2) in the atmosphere abrorb some of this IR radiation before it can escape into space, providing a net warming over what we'd have in the absence of an atmosphere.

3. Refracting telescopes have a glass lens as the primary light gathering optical element. The index of refraction of the lens is a function of wavelength, causing the focus to also be a function of wavelength:



4. That open water seems once to have existed on Mars implies it was once a warmer place. This suggests it had a thick atmosphere of CO_2 early on which retained heat. Over time, the CO_2 would dissolve in the water and form minerals at the bottom, as on Earth. Removal of CO_2 by this mechanism reduced the amount of greenhouse gases in the atmosphere and hence the temperature. Eventually temperatures dropped to the point where water froze. Eventually much of the CO_2 also froze out of the atmosphere, leaving it the thin, cold one it is today.

5. The ideal shape for the surface of the primary mirror of a reflecting telescope is a parabola.



6. The Earth's atmosphere is peculiar for having a large amount of oxygen (O_2).

7. Objects in the solar system aside from the sun and planets include

Asteroids (any three of these suffices)
Comets
Moons
Kuiper Belt Objets
Trans Neptunian Objects)

8. Resolving Pluto

$D = 2{,}300$ km

$a = 39.5$ AU

a)

$$\theta = \frac{D}{a} = \frac{2300 \text{ km}}{(39.5 \text{ AU})(1.5\times10^{8} \text{ km})} \qquad 206{,}265 \ ''/\text{radi}$$

$$\underline{\theta = 0.08''}$$

Strictly speaking, this is the angular size of Pluto as seen from the sun

If we observe Pluto from the Earth when Pluto is at opposition so that we are as close as we can be (the same side of the sun) the the Earth - Pluto distance becomes $39.5 - 1 = 38.5$ AU.

In this case,

$$\theta = 0.082''.$$

So it helps only a little to observe when Pluto is at opposition.

The diameter of Pluto is slightly smaller than the nominal 0.1" resolution of HST, so it remains unresolved.

8. b) If we want to resolve features 200 km across, we need to reduce θ by increasing the size of our telescope. (Note that 200 km resolution still gives only 11 resolved images across the diameter of Pluto, so this is still fairly crude.)

The diffraction limit for a telescope is

$$\theta = \frac{1.2\lambda}{D} \quad \left[\Rightarrow \; 2.5\times10^{5}\,\frac{\lambda}{D} \quad \text{for } \theta \text{ in arcseconds.}\right]$$

$$\lambda = 0.5\ \mu m = 5\times10^{-7}\ m$$

need θ for 200 km

$$\theta = \frac{200\ km}{(38.5\ AU)(1.5\times10^{8}\ \frac{km}{AU})} \cdot 206265\ ''/\text{radian}$$

$$\theta = 0.007''$$

so

$$D = \frac{2.5\times10^{5}\,\lambda}{\theta} = \frac{2.5\times10^{5}\,(5\times10^{-7}\ m)}{0.007''}$$

$$\boxed{D = 17.5\ m}$$

Nearly twice the size of the largest current telescopes!

9. a) This is a thermal balance problem. The input of the sun at Earth is 1366 $W m^{-2}$. At Mercury it is higher by the inverse square law:

$$F_{@Merc} = F_{@Earth} \cdot \left(\frac{d_{Merc}}{d_{Earth}}\right)^{-2}$$

$$= 1366 \left(\frac{0.387\ AU}{1\ AU}\right)^{-2}$$

$$\underline{F_{@Merc} = 9121\ W m^{-2}}$$

$F_{abs} = (1-a)F_{@Merc} = (1-0.12)(9121) = \underline{8026\ W m^{-2}}$ is absorbe

Now, this flux in must be balanced by the flux out (energy conservation):

$$F_{abs} = \sigma T^4$$

$$T = \left(\frac{F_{abs}}{\sigma}\right)^{1/4}$$

$$= \left(\frac{8026\ W/m^2}{5.67 \times 10^{-8}\ W m^{-2} K^{-4}}\right)^{1/4}$$

$$\boxed{T = 613\ K}$$

[Note that since we are given the power per unit area instead of the total power, the $4\pi R^2$ for the surface area of the planet drops out.]

9. b) $V_{esc} \geq 6 V_{th}$

M = Mercury mass
R = Merc. radius

$$V_{esc} = \sqrt{\frac{2GM}{R}} \qquad V_{th} = \sqrt{\frac{3kT}{m}}$$

solve for m when $\qquad$ m = molecular mass

$$V_{esc} = 6 V_{th}$$
$$V_{esc}^2 = 36 V_{th}^2$$

$$\frac{2GM}{R} = 36 \cdot \frac{3kT}{m} = 108 \frac{kT}{m}$$

$$m = \frac{54 kT R}{GM}$$

$$m = \frac{54 (1.38 \times 10^{-23} \text{ J K}^{-1})(613 \text{ K})(2.44 \times 10^{6} \text{ m})}{(6.67 \times 10^{-11} \text{ m}^3 \text{ s}^{-2} \text{ kg}^{-1})(3.3 \times 10^{23} \text{ kg})}$$

$$\underline{m = 5.23 \times 10^{-26} \text{ kg} = 30.5 \text{ AMU}}$$

(If you used T = 500 K, m = 25 AMU)

In the case of CO_2, m = 12 + 2(16) = 44 AMU.
By this criterion, Mercury <u>should</u> be able to retain CO_2, since its molecular mass exceeds the threshold we've calculated!

10.

a) $T = 32{,}000\ \text{K}$

Wien's law:

$$\lambda T = 2.9 \times 10^{-3}\ \text{K}\cdot\text{m}$$

$$\lambda = \frac{2.9\times10^{-3}\ \text{K m}}{32000\ \text{K}}$$

$$\underline{\lambda = 9\times10^{-8}\ \text{m} = 906\ \text{Å} = 0.09\,\mu\text{m}}$$

b) This λ is in the ultraviolet. The Earth's atmosphere is opaque to these UV photons, which can not be observed from the ground.

c) $E = hc/\lambda$

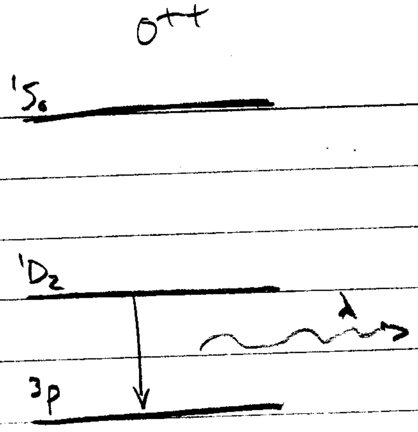
$$E = \frac{(4.136\times10^{-15}\ \text{eV s})(3\times10^{8}\ \text{m s}^{-1})}{9\times10^{-8}\ \text{m}}$$

$$\boxed{E = 13.7\ \text{eV}}$$

It takes 1 Rydberg (13.6 eV) to ionize hydrogen, so these photons are indeed energetic enough to do this.

10. d)

$^1D_2 \rightarrow {}^3p$
is the transition : ⟶



This transition
is 2.478 eV above the ground level

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

$$\lambda = \frac{hc}{E} = \frac{(4.136\times10^{-15}\,\mathrm{eV\cdot s})(3\times10^{8}\,\mathrm{s})}{(2.478\,\mathrm{eV})}$$

$$\underline{\lambda = 5\times10^{-7}\,\mathrm{m} = 5007\,\text{Å} = 0.5\,\mu\mathrm{m}}$$

In practive, much of the universe is opaque to the hard UV radiation produced by hot stars. These are usually reprocessed into other forms, like the Balmer lines of hydrogen and the 5007 Å line of oxygen.