Ex 3.5

Provide an argument showing that the interior of the ☉ is in LTE.

Consider deep interior $\Rightarrow$ gas completely ionized.

a) check how far a photon can travel before reabsorbed

$\bar{l}$ = mean freepath

b) compare with how much T changes (should stay the same for LTE) during l.

trickypart = adopt a cross-section for interaction

Thomson scattering (free e^-)

$\sigma_T = [D.1.1] = 6.65 \cdot 10^{-5}\ \mathrm{cm}^2$

area presented by an e^- to an incoming photon

- mean density $\bar{\rho}_\odot = \dfrac{M_\odot}{\frac{4}{3}\pi R_\odot^3} = 1{,}45\,g/cm^3$ / mean molecular weight

- number density : $n = \bar{\rho}_\odot / \mu \cdot m_H$ $= \left[\mu = 0.61 \right.$ for completely ionized gas with solar abundance 3.4.2 $\left. \right]$

$n = \dfrac{\bar{\rho}_\odot}{\mu\, m_H} = 1.4 \cdot 10^{24} / cm^3$

eq3.18 $\bar{l} = \dfrac{1}{n\sigma} = \dfrac{1}{1.4 \cdot 10^{24}/cm^3 \cdot 6.65 \cdot 10^{-25}\,cm^2} = 1\,cm$

LTE ok

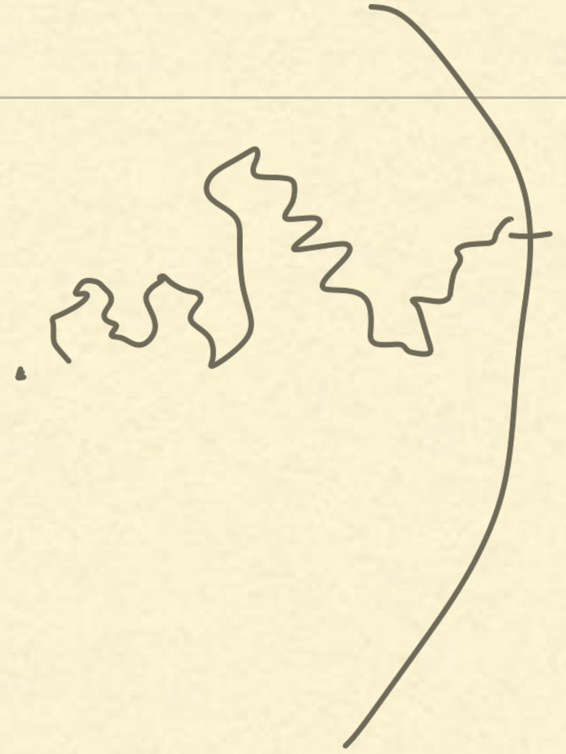
b) T change in $\odot$ over 1cm ?

$T_{central} = 1.6 \cdot 10^7 K$
$T_{surface} = 5781 K$
} table G.3

released photon reabsorbed w/in same T to an accuracy of $10^{-4} K$

gradient $\dfrac{T_{central} - T_{surface}}{R_\odot} = \dfrac{1.6 \cdot 10^7}{6.96 \cdot 10^{10}} = 2.3 \cdot 10^{-4} K/cm$

3.15



diffusion

"random walk"
from core to surface

energy drops from γ, X-ray to UV, optical, IR

— depends of type of ★

Reading recommendation app C

— The hydrogen atom

energy level diagram

n = principle quantum #

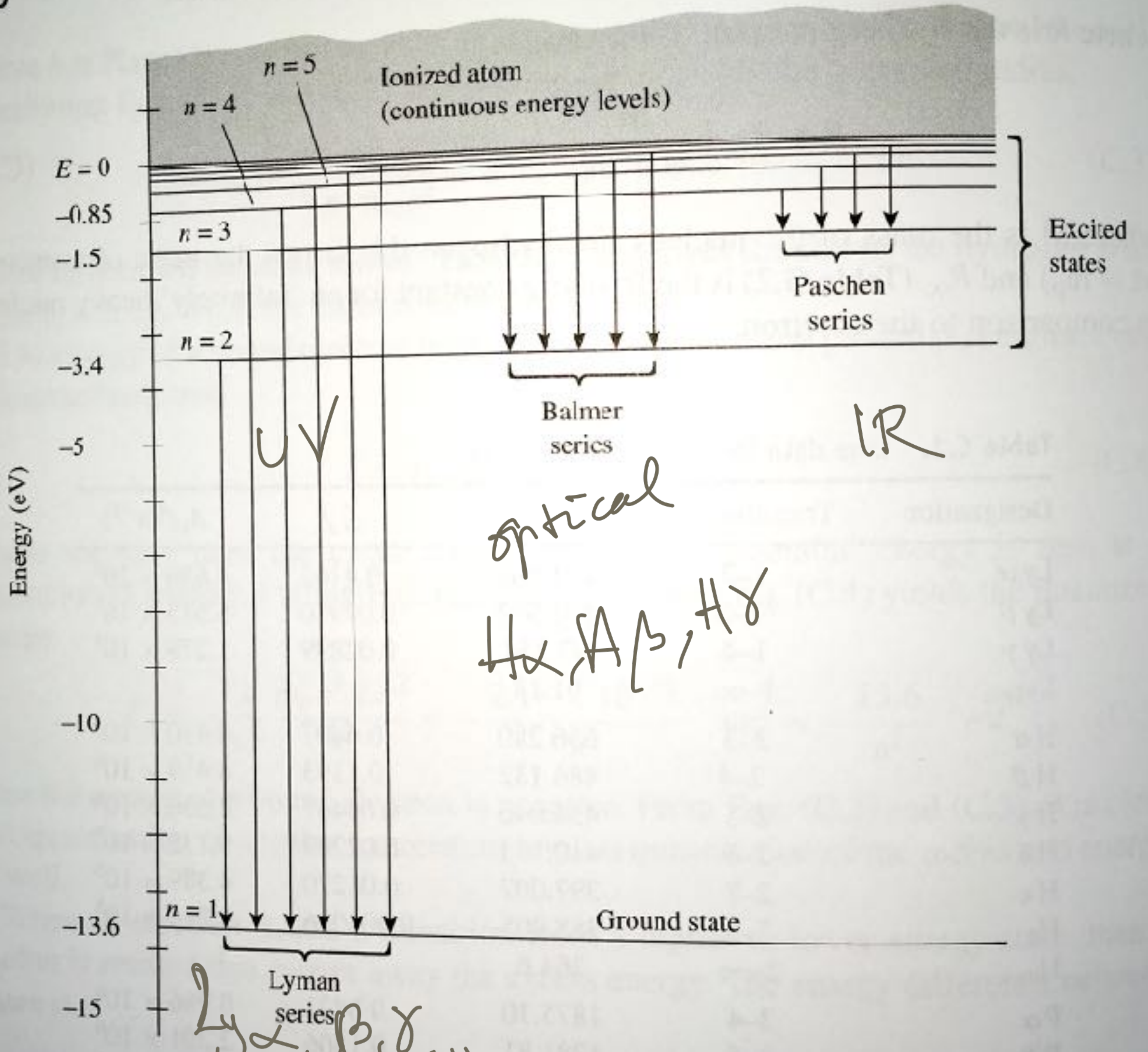


Figure C.1. Energy level diagram for hydrogen, showing the various series seen in the hydrogen spectrum.

Look at $n = 2 \rightarrow 1$ transition ⇐ Lyα

gas is ionized, or partially ionized

$T = 5000K$

$n = 1/cm^3$

$$\bar{t} = \frac{1}{n\underbrace{\langle v\sigma\rangle}} = \frac{1}{1 \cdot 6,0 \cdot 10^{-19}} = 5\,yr$$

table 3.2 → γ_{H-H} collision rate coefficient

What abt spontaneous de-excitation

$$t = \frac{1}{A_{ij}\,[s^{-1}]} = \frac{1}{4.7 \cdot 10^{8}/s} = 2.1 \cdot 10^{-9}\,s$$

table C.1 p 349

↑ Einsteins A-coefficient for transition from j to i (upper to lower)

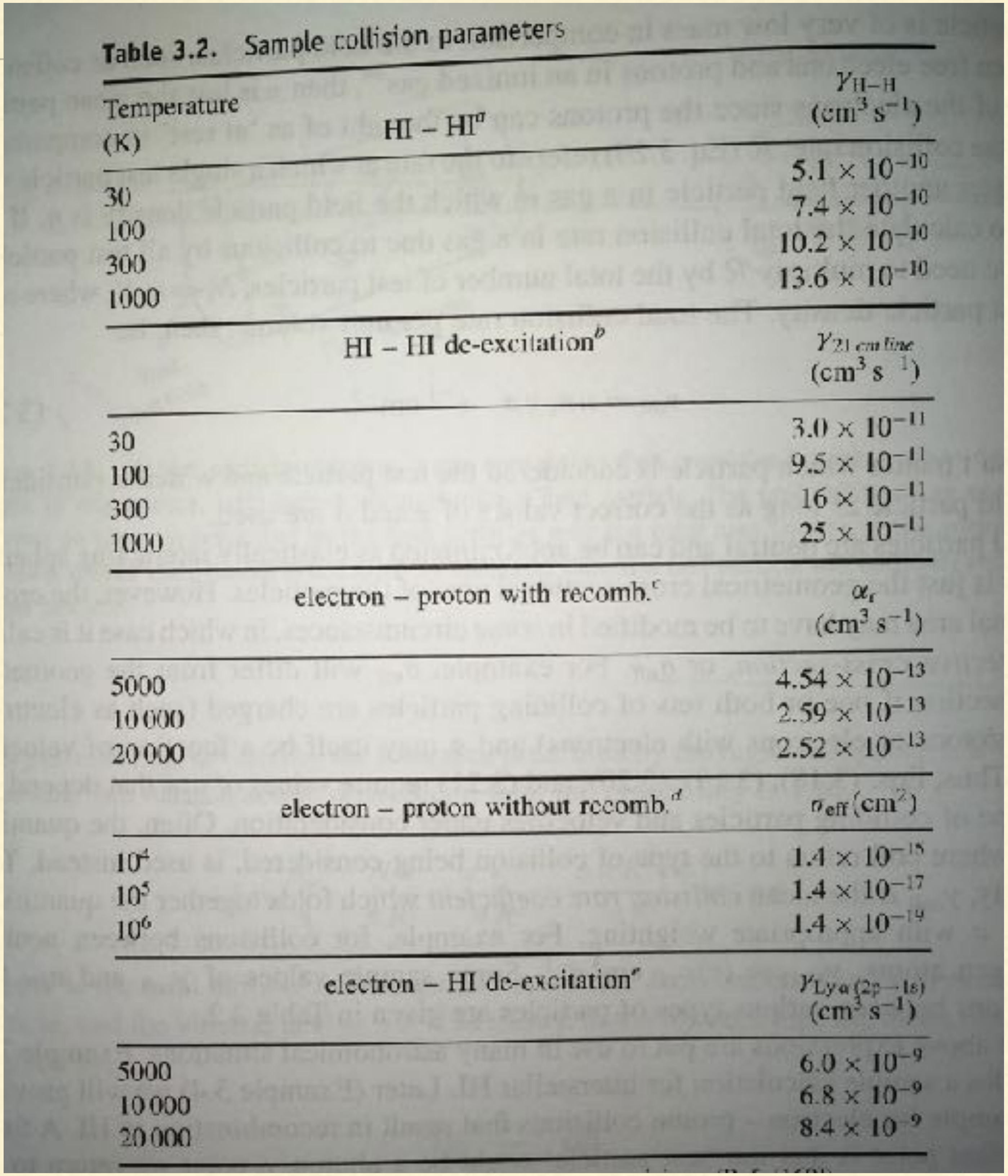


Table 3.2. Sample collision parameters

Temperature (K)	HI – HI[a]	$\gamma_{\mathrm{H-H}}$ (cm^3 s^{-1})
30		5.1×10^{-10}
100		7.4×10^{-10}
300		10.2×10^{-10}
1000		13.6×10^{-10}
	HI – HI de-excitation[b]	$\gamma_{21\ \mathrm{cm\ line}}$ (cm^3 s^{-1})
30		3.0×10^{-11}
100		9.5×10^{-11}
300		16×10^{-11}
1000		25×10^{-11}
	electron – proton with recomb.[c]	α_r (cm^3 s^{-1})
5000		4.54×10^{-13}
10 000		2.59×10^{-13}
20 000		2.52×10^{-13}
	electron – proton without recomb.[d]	σ_{eff} (cm^2)
10^4		1.4×10^{-15}
10^5		1.4×10^{-17}
10^6		1.4×10^{-19}
	electron – HI de-excitation[e]	$\gamma_{\mathrm{Ly}\alpha\,(2p-1s)}$ (cm^3 s^{-1})
5000		6.0×10^{-9}
10 000		6.8×10^{-9}
20 000		8.4×10^{-9}

$$\xcancel{\underbrace{\sum_{j\ge 1} A_{ji}\, n_j}_{\text{spontaneous de-excitation}} + \underbrace{\sum_{j\ne i} \gamma_{ji}\, n_j n}_{\text{collisions}} + \underbrace{\sum_{j>1} S_{ji}}_{\text{stimulated}} + \underbrace{\sum_{j<1} P_{ji}}_{\text{photon absorption}} + \underbrace{\sum_{k} C_{i}}_{\text{free state } e^-}}$$

stimulated de excitation due to strong radiation field

$$\boxed{\text{LTE is collision dominated}}$$

⇒ Simplify ⇒

Boltzmann's equation:

eq. 3.23

$$\overset{\text{\# atoms where } e^- \text{ are in level } n}{\underset{\text{\# atoms with } e^- \text{ in ground state}}{\frac{N_n}{N_1}}} = \frac{g_n}{g_1}\, e^{-\frac{\overset{\text{energy diff b/w } n \,\&\, 1}{\Delta E}}{kT}}$$

g_n = statistical weight $= 2n^2$

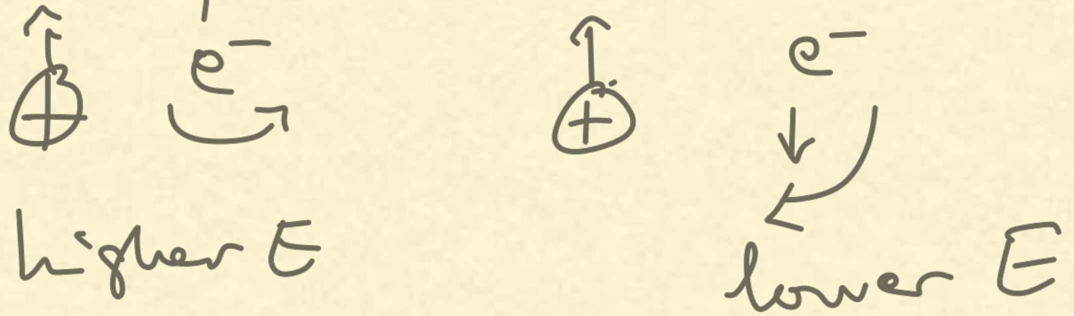
for H. $n=2 \Rightarrow g_2 = 8$

HI $\lambda = 21\,\text{cm}$ spectral line emission

$n = 1$ princ. quantum #

radiation due to a spin-flip transition

Does not happen often: How often?



$T = 100\,\text{K}$

$\Rightarrow \gamma_{21} = 9,5 \cdot 10^{-11}\ \text{cm}^3/\text{s}$ (table 3.2

$\bar{t} = \frac{1}{n\gamma} = 350\ \text{yr}$ ← mean-time b/w collisions

↑ density $(n = 1/\text{cm}^3)$

— spontaneous de-excitation 10^7 yrs

The *HI* Nearby Galaxy Survey (T*HI*NGS)

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