

# Ryden - Chapter 2 Solutions

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## 1 Exercise 1

We want to calculate the mean free path  $l$  of an arrow fired in a forest, where the trees have radius  $R$  and the average number of trees per unit area is  $\Sigma$ . Thinking about scaling, if the trees were more tightly packed, then  $l$  should decrease, so then  $l$  should be inversely proportional to  $\Sigma$ . Similarly, if the trees are larger the arrow will not travel as far, so  $l$  should be inversely proportional to  $R$ . Thus, the solution is  $l = (R\Sigma)^{-1}$ . Given that  $R = 1$  m and  $\Sigma = 0.005$  m<sup>-2</sup>, this means  $l = 200$  m. *Note* this answer isn't perfect, because the trees protrude forward toward the path of the arrow, but computing this correction is tricky because it involves an integral over the impact parameter  $b$  of the arrow with respect to the tree it hits. To a first approximation, the true answer is somewhere between 199 m and 200 m.

## 2 Exercise 2

This problem is identical to Exercise 1 but in three dimensions. The number density of stars is given by  $n_*$ , and the average stellar radius is  $R_*$ , meaning the cross-sectional area is  $\sigma = 4\pi R_*^2$ . The mean free path is again inversely proportional to  $n_*$  and  $\sigma$ , so  $l = (\sigma n_*)^{-1}$ . Given that  $n_* = 10^9$  Mpc<sup>-3</sup> and  $R_* = 7 \times 10^8$  m, this means  $l = 2.1 \times 10^{17}$  Mpc.

Similarly, if galaxies are spaced according to  $n_g = 1$  Mpc<sup>-3</sup> and  $R_g = 2000$  pc, then the mean free path to hit a galaxy is  $l_g = 20000$  Mpc. We see that a photon is fairly likely to pass through a galaxy, but not necessarily hit a star in that galaxy.

## 3 Exercise 3

Let us pretend our bodies are entirely made of water and we absorb all CMB photons that pass through us. Let us further assume that we are a nice, round 100 kg, and also a nice, spherical 1 m radius sphere, so that our volume is  $V = 4\pi/3$  m<sup>3</sup>. We know from the text that the number density of CMB photons is  $n_\gamma = 4.11 \times 10^8$  m<sup>-3</sup>.

TM: Finish this