Knierim_Week_1

April 29, 2020

0.1 Exercise 1

0.1.1 a)

[1]:
```
# textbook wavelength of Ly-alpha line
ly_alpha_wiki = 1215.67 # Å

# Ly-alpha line as seen in figure 1
ly_alpha_fig = 1213.5 # Å

delta_lambda = ly_alpha_fig-ly_alpha_wiki

# computing the redshift

z = delta_lambda/ly_alpha_fig

print("The 'redshift' is given by z = {:f}".format(z))

# determining the radial velocity of Andomeda

from scipy.constants import c

v = c * z

print("The radial velocity is given by v = {:.2f} m/s = {:.2f} km/s".
 ↪format(v,v*1e-3))
```

```
The 'redshift' is given by z = -0.001788
The radial velocity is given by v = -536093.64 m/s = -536.09 km/s
```

So, the Andromeda galaxy is actually moving towards us. It's spectrum is blueshifted, i.e. moved towards shorter wavelenghts, rather than redshifted.

0.1.2 b)

[2]:
```
# distance to Andromeda
D = 780 # kpc

# Hubble constant
H_0 = 71 #km/s/Mpc

# determining radial velocity using the Hubble law

v = H_0 * D*1e-3 # kpc -> Mpc

print("The radial velocity is given by v = {:.2f} km/s".format(v))
```

```
The radial velocity is given by v = 55.38 km/s
```

Of course, those are quite different values. The reason being that the Hubble law only measures the velocity due to the expansion of space, ignoring any relative motion of an object. However, Andromeda is "close" to us and moving towards the Milky Way. Therefore, the relative motion of the galaxy dominates over the expansion of space.

0.1.3 c)

[3]:
```
z = 0.05
H_0 = 71 #km/s/Mpc
from scipy.constants import c

v = c * z * 1e-3 # velocity in km/s

print("The radial velocity is given by v = {:.2f} km/s".format(v))

D = v/H_0

print("The distance is given by D = {:.2f} Mpc".format(D))
```

```
The radial velocity is given by v = 14989.62 km/s
The distance is given by D = 211.12 Mpc
```

0.2 Exercise 2

0.2.1 a)

For $\gamma + \gamma \to e^- + e^+$, the energy of the photons must at least be the same as the rest energy of the positron and electron, i.e. $h\nu_1 + h\nu_2 = m_{pos}c^2 + m_e c^2$. Assuming $\nu_1 = \nu_2$ and using that the mass of the positron is equal to the mass of the electron, we can write $E_\gamma = h\nu = m_e c^2$.

Therefore, the reaction starts to freeze out when the thermal energy is equal to the rest energy of the electron, $E_{th} = E_\gamma \Rightarrow k_b T = h\nu = m_e c^2$.

[4]:
```python
from scipy.constants import c, m_e, k

T = m_e*c**2/k

print("The reaction freezes out at T = {:.3e} K".format(T))
```

```
The reaction freezes out at T = 5.930e+09 K
```

0.2.2 b)

According to the lecture, the photon-baryon ratio at that time was 10^9.

[5]:
```python
# the temperature follows directly from the formula (where we devide by 1)
from scipy.constants import k

T = 1.5e10 #K

E_ph = k *T

print("The energy of the photons is given by {} J = {:.2f} MeV".format(E_ph,␣
 ↪E_ph*6241506479963.2))
```

```
The energy of the photons is given by 2.0709735e-13 J = 1.29 MeV
```

0.2.3 c)

Again, we need at least enough energy for the rest mass $E_{ph} + E_{D,0} = E_{p,0} + E_{n,0}$, so the energy of the photon is given by $h\nu = c^2(m_p + m_n - m_D)$

[6]:
```python
from scipy.constants import c, m_p, m_n, physical_constants, h
m_D = physical_constants["deuteron mass"][0]

E_ph = c**2*(m_p+m_n-m_D)

print("The energy of the photons is given by {} J = {:.2f} MeV".format(E_ph,␣
 ↪E_ph*6241506479963.2))
print("The frequency of the photon is given by {} Hz".format(E_ph/h))
```

```
The energy of the photons is given by 3.5641478723917843e-13 J = 2.22 MeV
The frequency of the photon is given by 5.37897696780615e+20 Hz
```

Deuterons are not very common due to the fact that they are used in many reactons of the Big Bang nucleosynthesis, e.g. for the creation of Helium. However, nucleosynthesis stopped when the temperature was sufficiently low. Therefore, some Deuterons were able to survive.