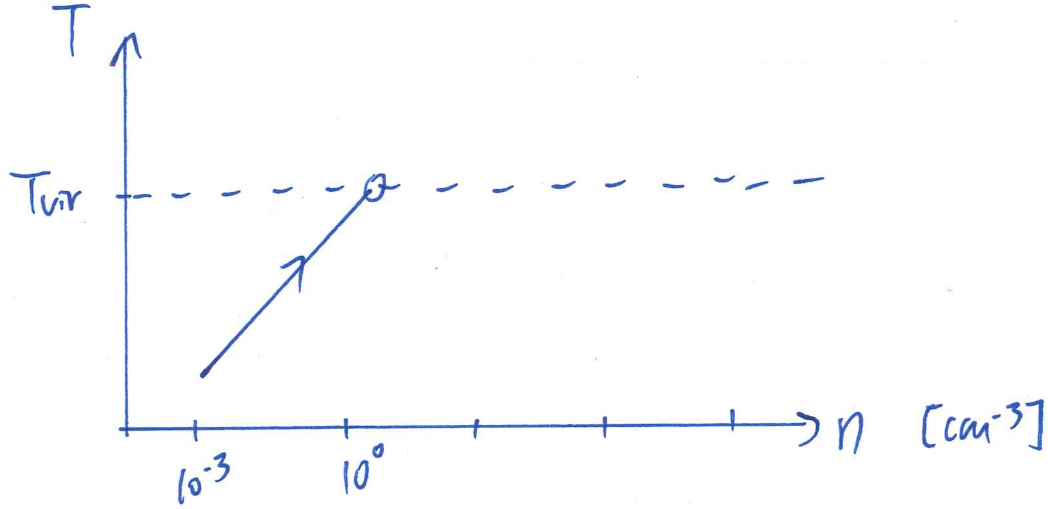
Recall from the discussion of adiabatic compression, we have $T \propto n^{2/3}$.



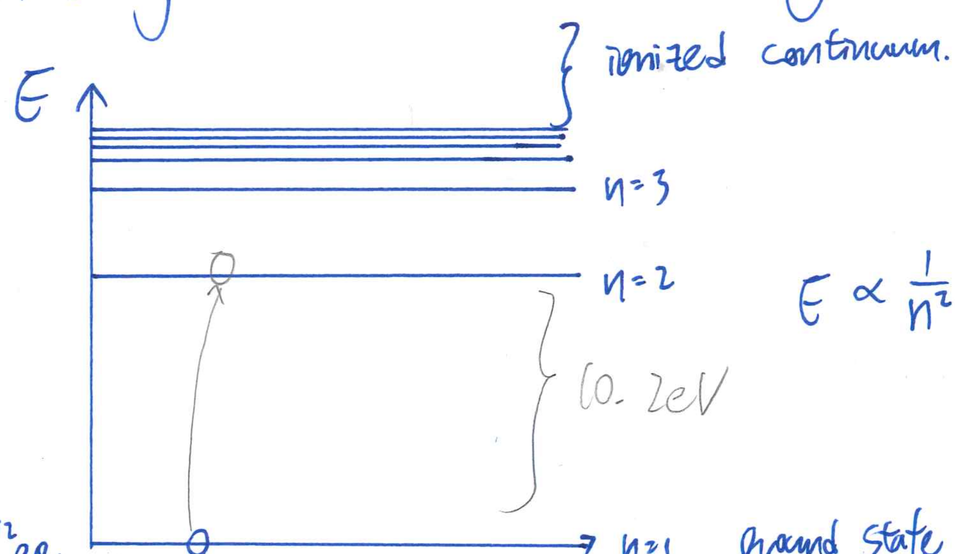
So, as the gas gets compressed, the temperature rises.
If the temperature of a gas cloud goes above T_{vir}, the collapse would not continue.

We need a way of getting rid of energy in the cloud.

⟶ Radiative cooling

⟶ in early universe — atomic hydrogen

Energy level diagram of atomic hydrogen.



1ev = "electron volt"
$= 1.6\times10^{-19}$ J $= 1.6\times10^{-12}$ erg.

Q: To collisionally excite hydrogen, how hot does the gas have to be? 03-03-2016

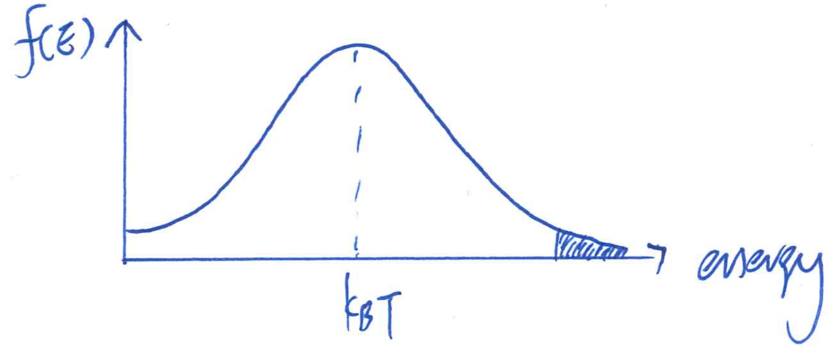
A: Simple guess :

$$10\,eV \cong k_B T$$

$$10^{-11}\,erg = 10^{-16} \cdot \frac{erg}{K} \cdot T$$

$$\boxed{T = 10^5 K} \quad !!?$$

In reality, the thermal energy of gas particles obeys a distribution



$$m_H \cdot \bar{v} \cong k_B T$$

→ Maxwell - Boltzmann distribution.

→ There is a fraction of particle (maybe small) which is energetic enough to excite hydrogen.

→ Find that $T_{gas} \sim 10^4 K$, this still can cool via excitation of H atoms.

→ Excited H atoms decay and emit Lyα photons.

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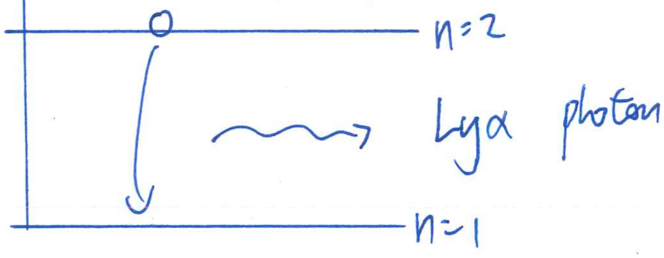
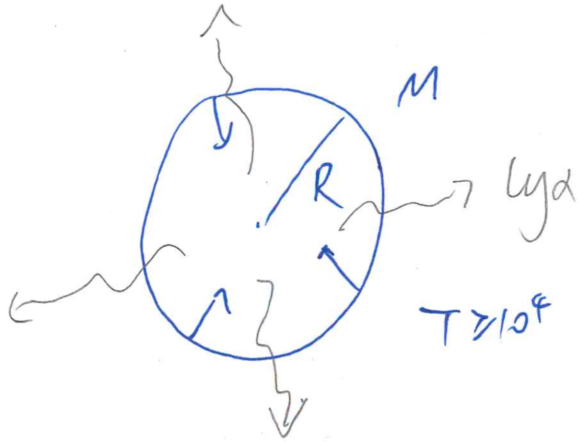


$$E_\alpha = h\nu_\alpha = \frac{hc}{\lambda_\alpha} = 10.2\,eV$$

$$\lambda_\alpha = 1216\,Å = 121.6\,nm.$$

As the cloud collapses, the gravitational potential energy is converted to radiative energy in Lyα photons.



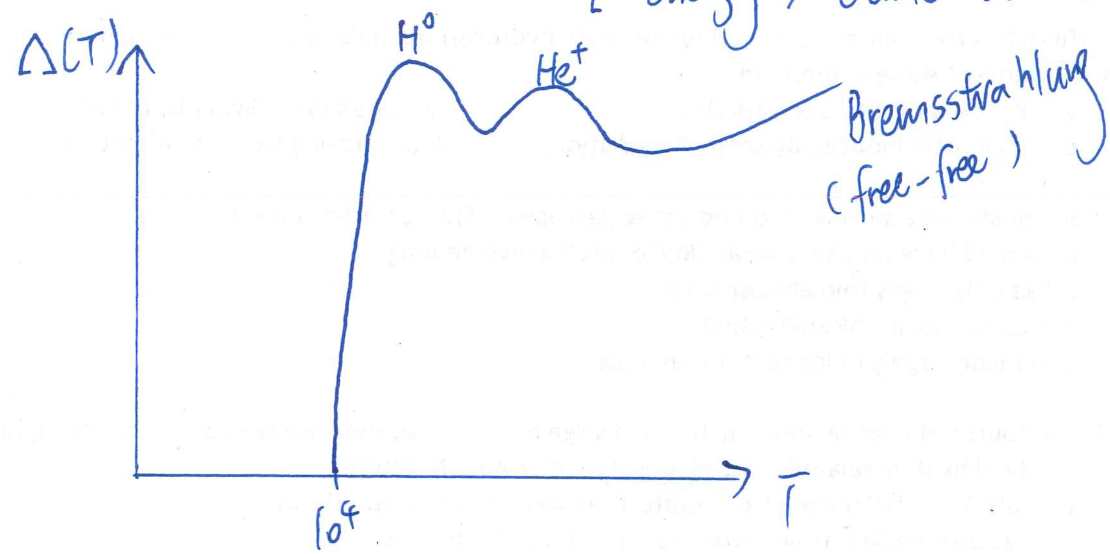
$$\text{time-scale for collapse} = t_{ff} = \frac{1}{\sqrt{G\rho}}$$

→ Estimate luminosity (energy / time) of Lyα radiation.

$$L_{Ly\alpha} \sim (GM^2/R) / t_{ff} \quad [erg\,s^{-1}].$$

Define: cooling rate $\Lambda = \Delta E / \Delta t \cdot \Delta V$ 03-03-2016

[energy / (time · volume)].



This is a typical cooling rate curve, which describes how efficient the gas cloud cools by emitting radiation as a function of temperature.

Above $T = 10^4$ K, the cooling is provided by the collisionally excited hydrogen; similarly for the He^+ ions at higher temperature. At even higher temperature the cooling is controlled by "free-free" emission.

We will talk about an important coolant, i.e. molecular hydrogen H_2, in the next lecture.