GAS CLOUDS IN BETWEEN STARS

"interstellar clouds"

(i) diffuse interstellar clouds
(mostly hydrogen)
density LOW — about 10 atoms/cm$^3$

(air at sea level $10^{19}$ atoms/cm$^3$
vacuum flask $10^5$ atoms/cm$^3$)
temperature low — about 100 K

(ii) dense molecular clouds
denser — about $10^6$ atoms/cm$^3$
colder — 10 - 30 K
cool and dense enough to form molecules
also contain dust grains
It is very difficult to detect hydrogen in molecular form \((\text{H}_2)\).

Much simpler to detect neutral (atomic) hydrogen.

In ground state of hydrogen atom, two possible arrangements of spin of electron & proton.

Spin same way

Opposite way

These two states have slightly different energies.
When the hydrogen atom changes from the 'spins aligned' state to the 'spins different' state, a photon is emitted. What region of the electromagnetic spectrum would this photon come from? Why?

Photon has wavelength 21 cm. Thus we can use radio waves to detect hydrogen atoms in interstellar space.
Molecular hydrogen is effectively invisible to astronomers.

But other molecules can be detected in the millimeter region (near IR-radio transition).

A useful molecule is carbon monoxide (CO).

Astronomers try to infer the amount of molecular hydrogen from the amount of CO.
Hot hydrogen gas is much easier to detect, if it is hot enough to ionize the hydrogen atom.

Then the hot gas (about 10,000 K) is visible in the optical region, looks reddish.

Q: What is the physical process which causes ionized hydrogen to glow?

Hot clouds of gas around hot stars are called HII regions. (means ionized)
STAR FORMATION

Q & Say we have a large cloud of gas & dust, 100 x mass of current solar system, but with radius 0.5 pc.

What will encourage it to collapse & form a star? What will prevent it?
Why might dust be a useful thing to have around when a star is forming?

(Hint: if you heat gas, will it expand or contract?)
Stars form from cool, dense clouds of gas & dust.

If the gas is heated (for example, by a newly formed young star), then it will expand.

Thus, the cloud needs to be cool so it can collapse further.

Dust will help keep the central regions of the cloud cool by absorbing radiation from nearby stars so they cannot heat the central core.
Simple criterion for gravitational collapse

Gravitationally bound

$\Rightarrow$ total energy negative

kinetic + potential energy

Simple example for basic physical understanding: uniform density sphere

Mass $M$, radius $R$, density $\rho$

$M = \frac{4}{3}\pi R^3 \rho$

Work out its total gravitational potential energy by assembling it in shells from $\infty$
If assemble shells thru radius \( r \), how much mass to bring in next shell, thickness \( dr \)?

**Shell volume**

\[ dV = 4\pi r^2 \, dr \]

**Mass**

\[ dm = 4\pi r^2 \rho \, dr \]

Mass already assembled inside \( r \)

\[ m(r) = \frac{4}{3} \pi r^3 \rho \]
For two point masses $m_1$ and $m_2$, $r$ apart, the gravitational potential energy $U = -\frac{G m_1 m_2}{r}$.

$m_1$ is $M(r)$

$m_2$ is shell mass $dm$

\[
dU(r) = -\frac{G M(r)\, dm}{r} = -G \frac{4}{3} \pi r^3 \rho \cdot 4\pi r^2 \rho \, dr \frac{1}{r} = -G \frac{16}{3} \pi^2 r^4 \rho \, dr
\]

Total potential energy

\[
U = \int_0^R dU(r) = -G \frac{16}{3} \pi^2 \rho \int_0^R r^4 \, dr
\]
Integrating, we get

$$U = -\frac{3}{5} \frac{G M^2}{R}$$

Kinetic (thermal) energy is \( \frac{3}{2} kT \) per particle.

For particles of mass \( m \), there are \( \frac{M}{m} \) particles in total so

total kinetic energy = \( \frac{3}{2} \frac{M}{m} kT \)

For cloud to be gravitationally bound we find

$$\frac{3}{5} \frac{G M^2}{R} \geq \frac{3}{2} kT \frac{M}{m}$$

potential \( \geq \) thermal
So \[ \frac{M}{R} \geq \frac{5}{2} \frac{kT}{Gm} \]

But, \( M, R \) are not independent

\[ \varrho = \frac{4}{3} \pi \frac{M}{R^3} \]

We can use this to estimate size (or mass) to make a cloud gravitationally bound.

Make \( \geq \) into = for bound/unbound boundary

eliminate \( M \)

\[ \frac{4}{3} \pi \frac{R^3 \varrho}{R} = 5kT/2Gm \]

"Jeans length" \( R_J = \sqrt{\frac{15kT}{8\pi Gm\varrho}} \)
Since $\sqrt{\frac{15}{8\pi}} \approx 1$ we say that

$$R_J \approx \sqrt[3]{\frac{kT}{Gm_p}}$$

(assumptions like constant density also produce approx. relation but it's close)

Jean's mass is the smallest size for which the cloud is gravitationally bound.

Can also eliminate $R$ and get smallest mass

"Jean's mass" $= 4 \left(\frac{kT}{Gm}\right)^{3/2} \rho^{-1/2}$. 
MAGNETIC FIELDS

Faraday's law:

\[ \oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt} \]

integral around closed path

magnetic flux through surface

If the material has some conductivity, currents will flow to oppose change in magnetic flux

\[ \Rightarrow \text{flux constant ("frozen in") } \]
Electric current induced in loop could go in 2 directions; but one will violate energy conservation, because it will create a stronger magnetic field, speed up loop, etc. .

So current will oppose change in magnetic flux.