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 (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

Q 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

$\boxed{Q}$ 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 × mass of current solar system, but with radius 0.5 pc.

What will encourage it to collapse & form a star? What will prevent it?

Q.

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

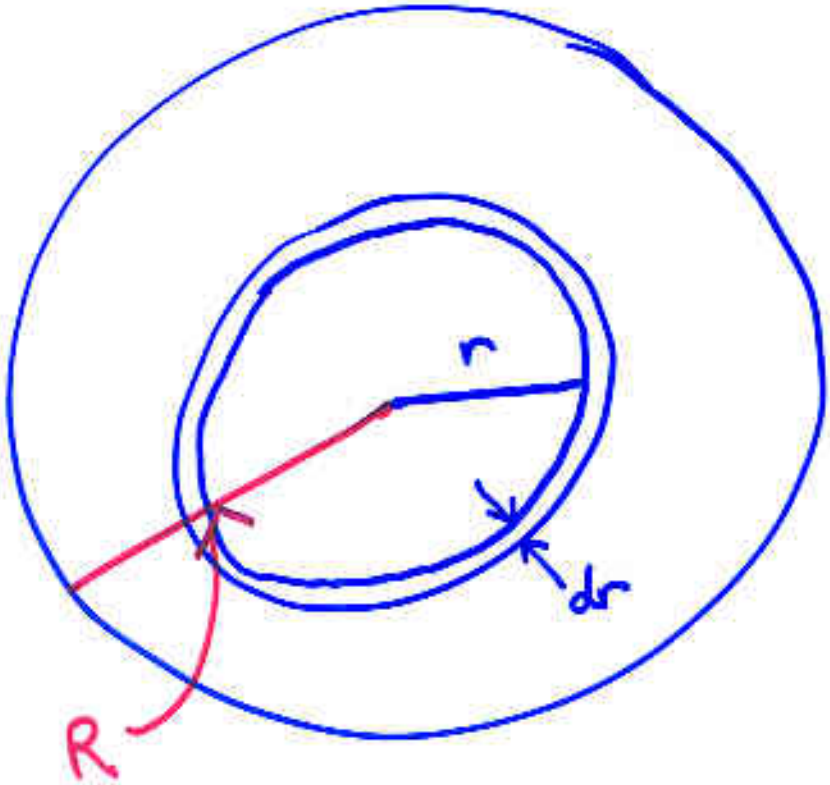
kinetic + potential energy

Simple example for basic physical understanding : uniform density sphere

Mass M, radius R, density ρ

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

Work out its total gravitational potential energy by assembling it in shells from ∞



If assemble shells thru radius r, how much work 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 is $m(r) = \frac{4}{3}\pi r^3 \rho$

For two <u>point</u> masses m_1 & m_2, r apart

grav. potential energy $U = -\dfrac{G m_1 m_2}{r}$

m_1 is $M(r)$

m_2 is shell mass dM

$$dU(r) = -\frac{G\,M(r)\,dM}{r}$$

$$= -\frac{G \cdot \frac{4}{3}\pi r^3 \rho \cdot 4\pi r^2 \rho\, dr}{r}$$

$$= -G \cdot \frac{16}{3}\pi^2 r^4 \rho\, dr$$

Total potential energy

$$U = \int_0^R dU(r)$$

$$= -G \cdot \frac{16}{3}\pi^2 \rho \int_0^R r^4\, dr$$

Integrating, we get

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

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

$$\underbrace{\frac{3}{5} G M^2 / R}_{\text{potential}} \geq \underbrace{\frac{3}{2} kT \frac{M}{m}}_{\text{thermal}}$$

So $\frac{M}{R} \geq \frac{5}{2}\frac{kT}{Gm}$

But, M, R are not independent

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

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

Make $\geq$ into $=$ for bound/unbound boundary

eliminate M

$$\frac{4}{3}\pi R^3 \rho / R = 5kT/2Gm$$

"Jeans length" $R_J = \sqrt{\frac{15kT}{8\pi G m \rho}}$

Since $\sqrt{\frac{15}{8\pi}} \simeq 1$ we say that

$$R_J \simeq \sqrt{\frac{kT}{G m \rho}}$$

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

Jeans mass is the <u>smallest</u> size for which the cloud is gravitationally bound

Can also eliminate R and get smallest mass

$$\text{"Jeans mass"} = 4\left(\frac{kT}{Gm}\right)^{3/2} \rho^{-1/2}.$$

MAGNETIC FIELDS

Faraday's Law:

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

magnetic flux thru surface

integral around closed path

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

→ flux constant ("frozen in")

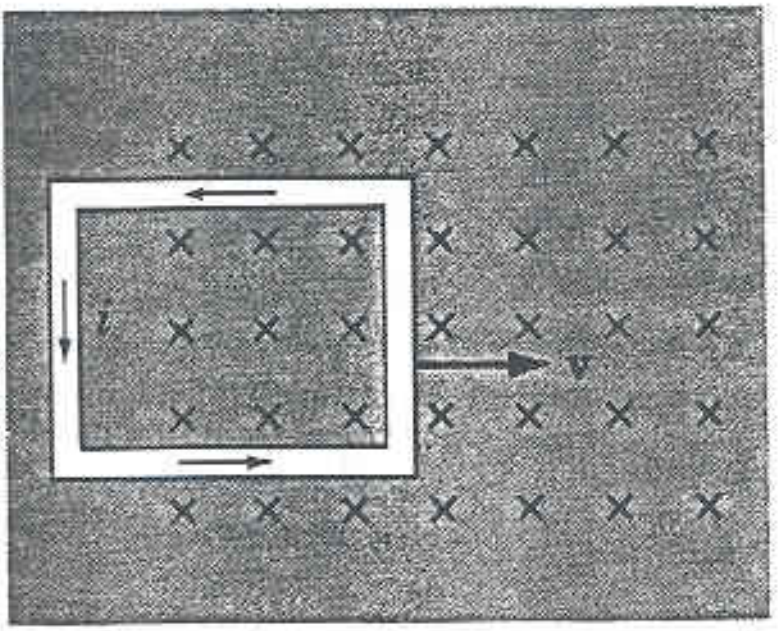


FIG 31-3. *A conducting loop one end of which moves through a transverse magnetic field* **B**.

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 <u>oppose</u> change in magnetic flux