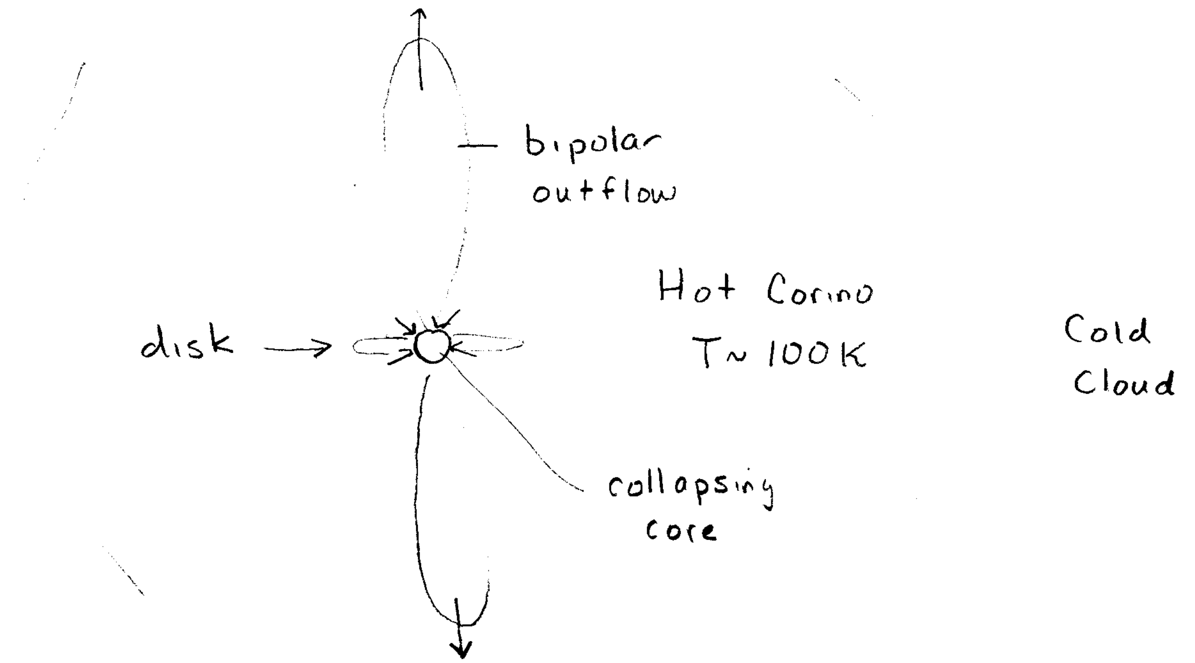
C/P 740 Winter Quarter 2008

Answers To Midterm

1.



a) Collapsing Core: heating up adiabatically to eventually form a star when nuclear reactions turn on

b) Bipolar Outflow: Fast-moving gas & dust causing shock waves as it strikes ambient material. Molecules such as SiO sputtered off grain cores. Methanol (CH_3OH) also present.

c) Disk: Dense gas & dust, rather planar, rotating around core, eventually to become a protoplanetary disk.

d) Hot Corino: richest in chemistry, with hydrogen-rich organic molecules (e.g. CH_3OH, $HCOOCH_3$, CH_3OCH_3) prevalent along with more exotic types. No grain mantles detected.

Formation of Molecules: In previous cold era, both surface chemistry + gas-phase chemistry followed by accretion lead to large mantles. These evaporate as T rises leading to high abundances of species such as methanol that are precursors for a warm gas-phase chemistry that leads to more complex organic species.

2. CO

$$\begin{array}{c} \overline{}\ J+1 \\ \downarrow \\ \overline{}\ J \end{array}$$

$\nu = 2B(J+1)$ $B = 57.91$ GHz (homew

1 THz = 1000 GHz

(a) $\underline{\nu = 115.82(J+1)}$

$J+1 \rightarrow J$	ν (THz)
$9 \rightarrow 8$	1.042
$10 \rightarrow 9$	1.158
$11 \rightarrow 10$	1.274
$12 \rightarrow 11$	1.390
$13 \rightarrow 12$	1.505
$14 \rightarrow 13$	1.621
$15 \rightarrow 14$	1.737
$16 \rightarrow 15$	1.853

Note: only pure rotational transitions can be seen

Consider $v = 1 \rightarrow 0$

$\omega_e \sim 2400\ cm^{-1}$

$\nu = c\omega_e = 7.2 \times 10^{13}\ s^{-1}$

$= 72$ THz

too large

(b) $T = 300$ K $\quad P_J = \dfrac{(2J+1)\, e^{-E_J/kT}}{q_{rot} = kT/hB}$

$J = 16$ $\quad E_J = hBJ(J+1) = hB\ 16 \times 17$

$h = 6.6261 \times 10^{-27}$ erg-s $\quad k = 1.3807 \times 10^{-16}$ erg/K

$B = 5.791 \times 10^{10}\ s^{-1}$

$P_{16} = 33 \exp(-2.52) / 107.95 = 0.025 \quad 2.5\%$

(c) Black body continuum is emitted by dust particles.

Wien displacement law (peak emission) $\quad \lambda_{max} T = 2.90 \times 10^6$ nm-K

$\lambda_{max} = 9.67 \times 10^3$ nm

$= 9.67 \times 10^{-4}$ cm

$\nu = \dfrac{c}{\lambda} = 3.101 \times 10^{13}$ Hz

($c = 2.9979 \times 10^{10}\ cm\ s^{-1}$) $\quad \nu = 31.01$ THz

In the range 1.0 - 1.9 THz, one can only see the low fre

tale of the radiation.

3. a) Use quantum expression: $\sigma_R = \pi \hbar^2 / 2\mu E_T$ $\quad l=0$ only

$\mu \approx m_e$ $$k(T) = \int_{E_T=0}^{\infty} v \, \frac{\pi \hbar^2}{2\mu E_T} P(E_T)\, dE_T$$

$E_T = \frac{1}{2}\mu v^2 \qquad v = \left[\frac{2E_T}{\mu}\right]^{1/2}$

$$P(E_T)\,dE_T = \left(\frac{4}{\pi}\right)^{1/2} E_T^{1/2} (k_B T)^{-3/2} e^{-E_T/k_B T}$$

$$k(T) = \left(\frac{2}{\mu}\right)^{1/2} \frac{\pi \hbar^2}{2\mu} \left(\frac{4}{\pi}\right)^{1/2} \frac{1}{(k_B T)^{3/2}} \underbrace{\int_0^{\infty} e^{-E_T/k_B T}\, dE_T}_{k_B T}$$

$$k(T) = \sqrt{2\pi}\, \frac{1}{\mu^{3/2}} \frac{\hbar^2}{(k_B T)^{1/2}} = \sqrt{\frac{2\pi}{k_B \mu^3 \cdot 300}}\, \hbar^2 \left(\frac{300}{T}\right)^{1/2}$$

$$k(T) = 4.98 \times 10^{-7} \left(300/T\right)^{1/2} = 2.73 \times 10^{-6} \text{ cm}^3 \text{ s}^{-1}$$

If b considered to be continuous:

cantry $k_L = 2\pi e \sqrt{\alpha/\mu} = 2\pi e \sqrt{\dfrac{\alpha}{m_e}} = 1.41 \times 10^{-7} \text{ cm}^3 \text{ s}^{-1}$

b) $k_{TS} = k_L \left[0.4767 x + 0.6200\right]$ $\qquad \mu_D(B) = 1.0 \times 10^{-18}$ esu-cm

$\alpha = 2.0 \times 10^{-24}$ cm^3

$$x = \frac{\mu_D}{\sqrt{2\alpha k_B T}} = 13.46 \left(\frac{42.55}{T^{1/2}}\right) \qquad T = 10\text{K}$$

$k_{TS} = k_L(7.04)$ $\qquad k_L = 2\pi e \sqrt{\alpha/\mu} = 2.095 \times 10^{-9} \text{ cm}^3 \text{ s}^{-1}$

$\frac{1}{\mu} = \frac{1}{m_A} + \frac{1}{m_B}$ $\qquad \therefore k_{TS} = 1.475 \times 10^{-8} \text{ cm}^3 \text{ s}^{-1}$

$\mu = 2.5 \text{ amu}/N_A$

$\alpha = 2 \text{ Å}^3 = 2.0 \times 10^{-24} \text{ cm}^3$

4. (a) $N_H = 1.8 \times 10^{21} A_V \Rightarrow A_V = 1$

$\therefore$ real $m_V = +4$ (stronger) $\quad M_V = 0$ (A0)

$m - M = 5.0 \log (r/10pc) \quad 0.8 = \log_{10} (r/10pc)$

$r = 10pc \; 10^{0.8} = 63.1$ pc

(b) H is very abundant & it is mainly in $n_L = 1$.

Lyman α

$$n_u = 2 \uparrow n_L = 1$$

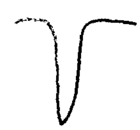
$E = -13.60 \text{ eV}/n^2$

$$\Delta E = h\nu = -13.60 \text{ eV} \left[\frac{1}{4} - 1 \right] = 10.20 \text{ eV}$$

$$h = 6.626 \times 10^{-27} \text{ erg} \cdot \text{s} \; \frac{6.242 \text{ eV}}{1 \text{ erg}} = 4.136 \times 10^{-15} \text{ eV}$$

$\therefore \nu = 2.466 \times 10^{15} \text{ s} \quad \lambda = c/\nu = 1.216 \times 10^{-5} \text{ cm} = 121.6$
(UV)

(c) The Doppler Effect allows astronomers to distinguish stellar and interstellar radiation



stellar lines are broad due to rapid rotation

(d) Absolute extinction is not easy, but astronomers can easily tell <u>reddening</u>, or differential, extinction

(e) For a diffuse cloud $n_H \sim 10^2 \text{ cm}^{-3}$

$N_H = n_H L \Rightarrow L = 1.8 \times 10^{19}$ cm ~ 6 pc