

# THE SUN

MASS (deduced from accelerations of planets, knowing G)

$$= 2 \times 10^{30} \text{ kg}$$

$$= 333,000 \times \text{mass of Earth} = 99.86\% \text{ of S.S.}$$

RADIUS = 696,000 km

MEAN DENSITY = 1.41 x water (Compare over planets)

LUMINOSITY =  $4 \times 10^{23}$  kilowatts\*

(Each square yard of solar surface radiates equivalent to 70,000 Horsepower!)

CHEMICAL COMPOSITION (from spectrum)

~70% HYDROGEN

~28% HELIUM

~2% ALL OTHER ELEMENTS

Compare Jupiter  
H:He ~2:1

SURFACE TEMPERATURE (from spectrum)

~5800°K

\* Total power consumption of all industrial nations on Earth is ~  $10^9$  kilowatts.

# HOW

does the Sun produce its energy supply?

Fossil blue-green algae on Earth for several billion years → released one million times more energy per unit mass than TNT explosion!

does the Sun hold itself up against gravity?

Surface gravity  $\sim 28 \times$  Earth's at surface

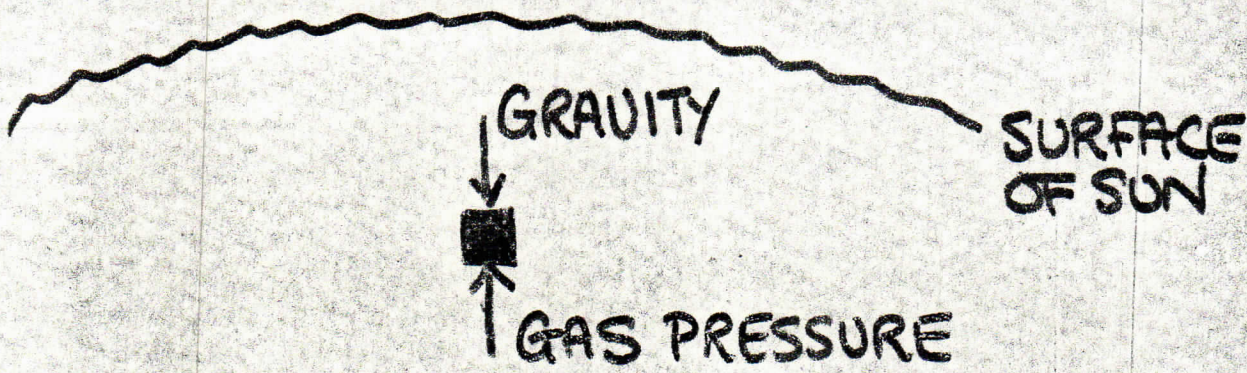
Free fall time surface → centre  $\sim$  20 minutes

Self-gravity of Sun, if unopposed, would cause collapse in  $\sim 20$  minutes — but it has been stable for billions of years!

does the Sun not cool off, when it is much hotter than its surroundings

SUN MUST BE IN WELL-BALANCED EQUILIBRIUM:

1. Mechanical — gravity balanced by other forces so Sun does not shrink
2. Energetic — energy supply makes up losses, so Sun does not cool.



TO SUPPORT ■ MOVING NEITHER UP NOR DOWN, INWARDS INCREASE IN GRAVITATIONAL "SQUEEZING" MUST BE BALANCED BY INWARDS INCREASE IN GAS PRESSURE.

TO SUPPORT "HYDROGEN SUN", WOULD NEED TEMPERATURE, PRESSURE, DENSITY INCREASING INWARDS TO CENTRE-SUN VALUES OF ABOUT:

- TEMPERATURE - 15 million Kelvin
- PRESSURE - 450 billion Earth atmospheres
- DENSITY - 360 x water

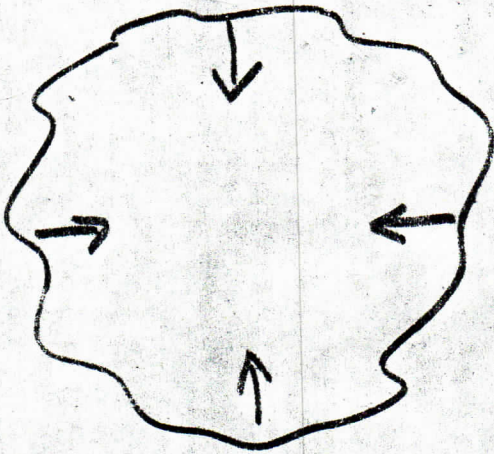
COULD SUCH CONDITIONS

- a) EXIST
- b) BE MAINTAINED FOR BILLIONS OF YEARS

??

# Energy Release from Gravitational Collapse?

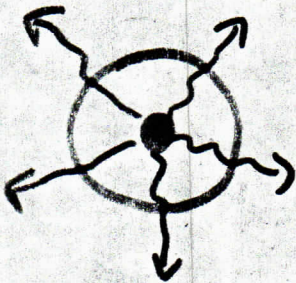
1.



Sphere of cold hydrogen

GRAVITATIONAL SELF-  
ATTRACTION → CONTRACTION  
→ COMPRESSION AND  
HEATING OF INTERIOR

2.



OUTWARD FLOW OF RADIATION  
FROM DENSE HOT  
INTERIOR

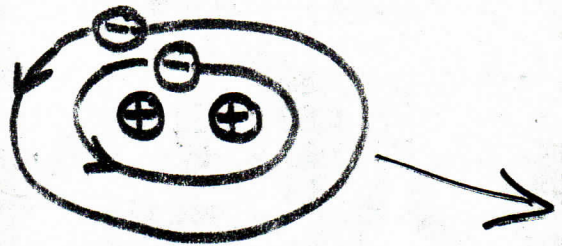
SUN WOULD HAVE TO SHRINK BY ABOUT  
400 FEET PER YEAR TO MAINTAIN OBSERVED  
ENERGY OUTPUT.

~ 150 MILLION YEARS AGO WOULD HAVE  
FILLED EARTH'S ORBIT.

CONTRADICTS EVIDENCE OF FOSSIL  
RECORD OF LIFE ON EARTH

# PROCESSES IN HYDROGEN AT INCREASING TEMPERATURE

1. Temp  $\sim 300^\circ\text{K}$   
ROOM TEMPERATURE



HYDROGEN MOLECULAR.

MOLECULAR SPEEDS  $\sim 2 \text{ km/sec}$

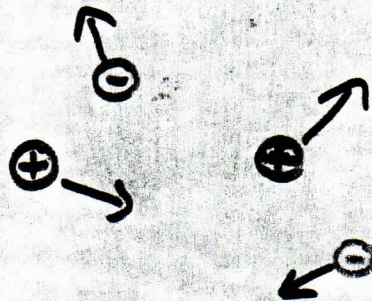
2. Temp  $\sim$  few thousand  $^\circ\text{K}$  - FURNACE



MOLECULAR SPEEDS  $\sim 5 \text{ km/sec}$

COLLISIONS BREAK MOLECULES INTO ATOMS

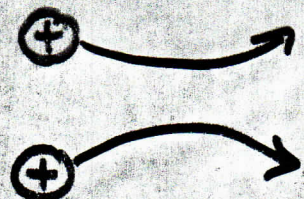
3. Temp  $\sim 10,000^\circ\text{K}$   
ATOMIC SPEEDS  
 $\sim 15 \text{ km/sec}$



COLLISIONS BREAK ATOMS INTO SEPARATED PROTONS AND ELECTRONS. "IONISED HYDROGEN"

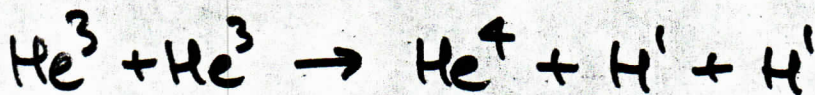
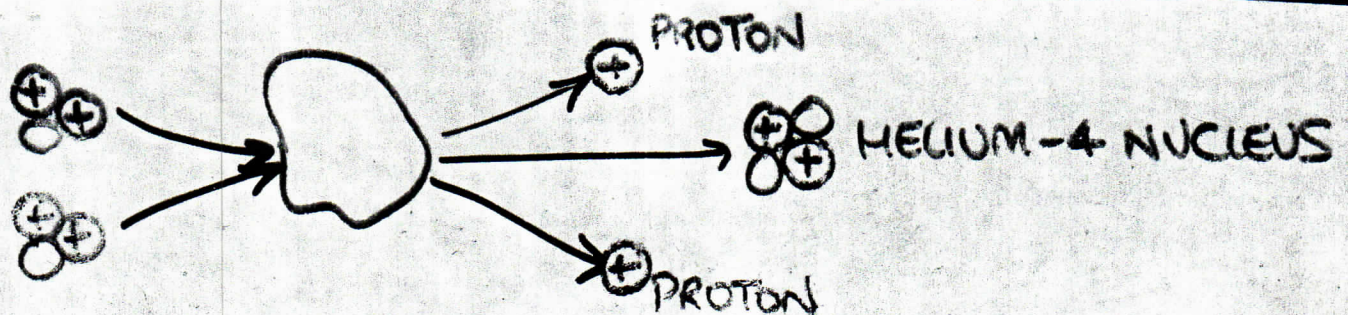
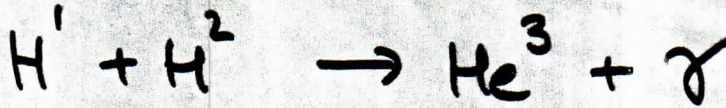
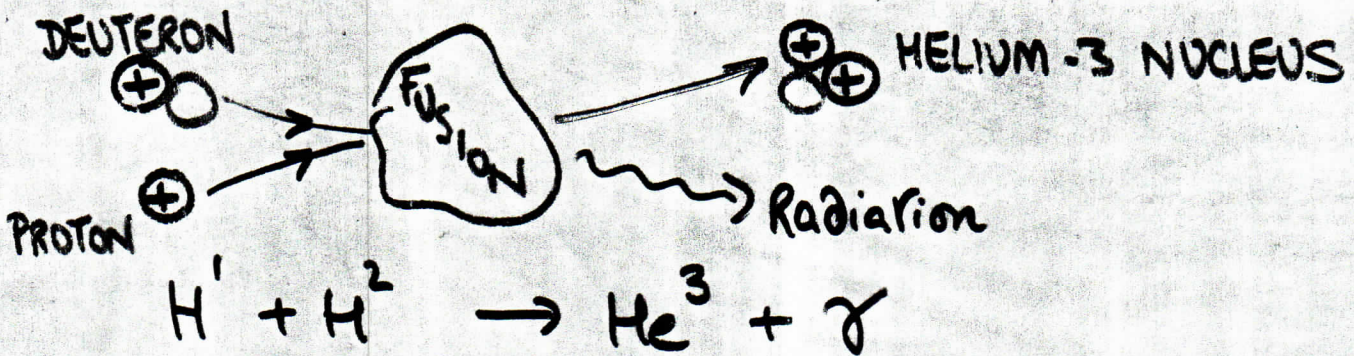
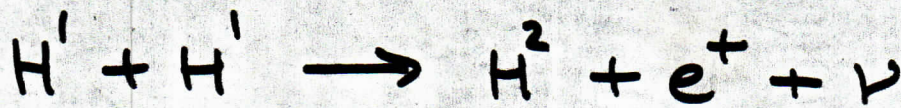
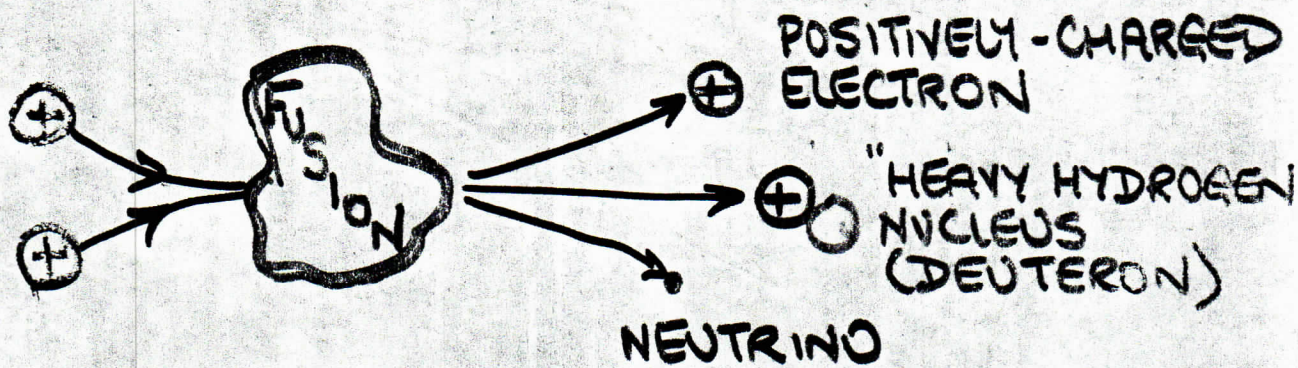
4. Temp  $\sim 1,000,000^\circ\text{K}$   
PROTON SPEEDS  $\sim 150 \text{ km/sec}$

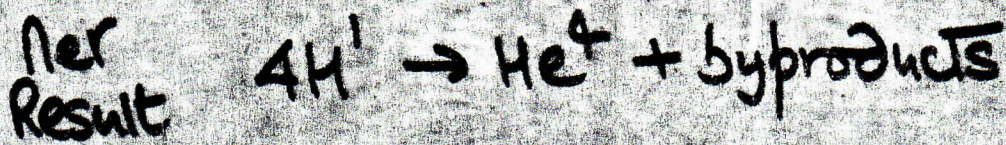
Repulsion of like electrical charges prevents very close collisions.



# HYDROGEN (PROTON) FUSION AT TEMPERATURE $\sim 10,000,000$ K

SOME PROTON-PROTON COLLISIONS OCCUR AT SUCH HIGH SPEEDS THAT ELECTRICAL REPULSION OF  $\oplus$  CHARGES CANNOT KEEP PROTONS BEYOND RANGE OF NUCLEAR ATTRACTIVE FORCE.





Mass of  $He^4 + \text{byproducts}$  is only 99.3% of mass of 4 protons.

• MASS VANISHES DURING THESE FUSION REACTIONS.

CORRESPONDING AMOUNT OF ENERGY IS RELEASED ( $E = mc^2$ )

Annihilation of 1 gm/sec  $\rightarrow 10^{11}$  watts

(This is 100 x energy usage of industrialised world)

# The Solar Energy Budget

DEBIT :  $4 \times 10^{23}$  kilowatts radiating from surface

CREDIT : Wattage generated in dense, hot core by  $H \rightarrow He$  fusion.

EQUATE THESE TO EXPLAIN OBSERVED EQUILIBRIUM :-

To produce  $4 \times 10^{23}$  kilowatts in solar interior, must convert approximately  $10^{39}$  protons/second into helium nuclei.

NO. OF PROTONS IN SUN  $\sim 10^{57}$  (from mass of Sun)

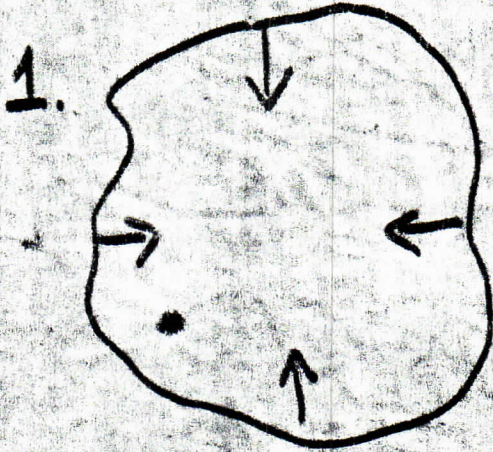
MAXIMUM "LIFETIME" OF  $H \rightarrow He$  FUSION-SUPPORTED EQUILIBRIUM  $\sim \frac{10^{57}}{10^{39}}$  seconds

$\sim 30$  billion years

IN FACT, NOT ALL SOLAR PROTONS CAN BE USED FOR FUSION IN CORE (CANNOT HAVE ENTIRE SUN A DENSE HOT "CORE"). "LIFETIME"  $\sim$  10 billion years

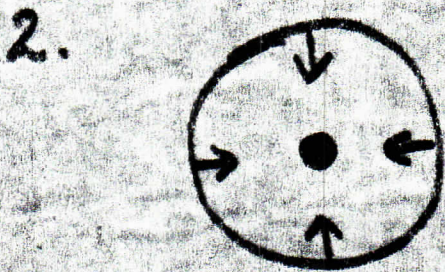


# Gravitational Collapse of Hydrogen Cloud (Re-visited)



Sphere of cold hydrogen molecules.

CONTRACTS UNDER GRAVITY  
COMPRESSES, HEATS  
INTERIOR



INTERIOR  $\rightarrow$  ATOMS  
IONS  
AS COLLAPSE PROGRESSES  
STILL NO INTERNAL ENERGY  
SOURCE UNTIL CENTRAL  
TEMPERATURE REACHES ABOUT  
10 MILLION DEGREES, K

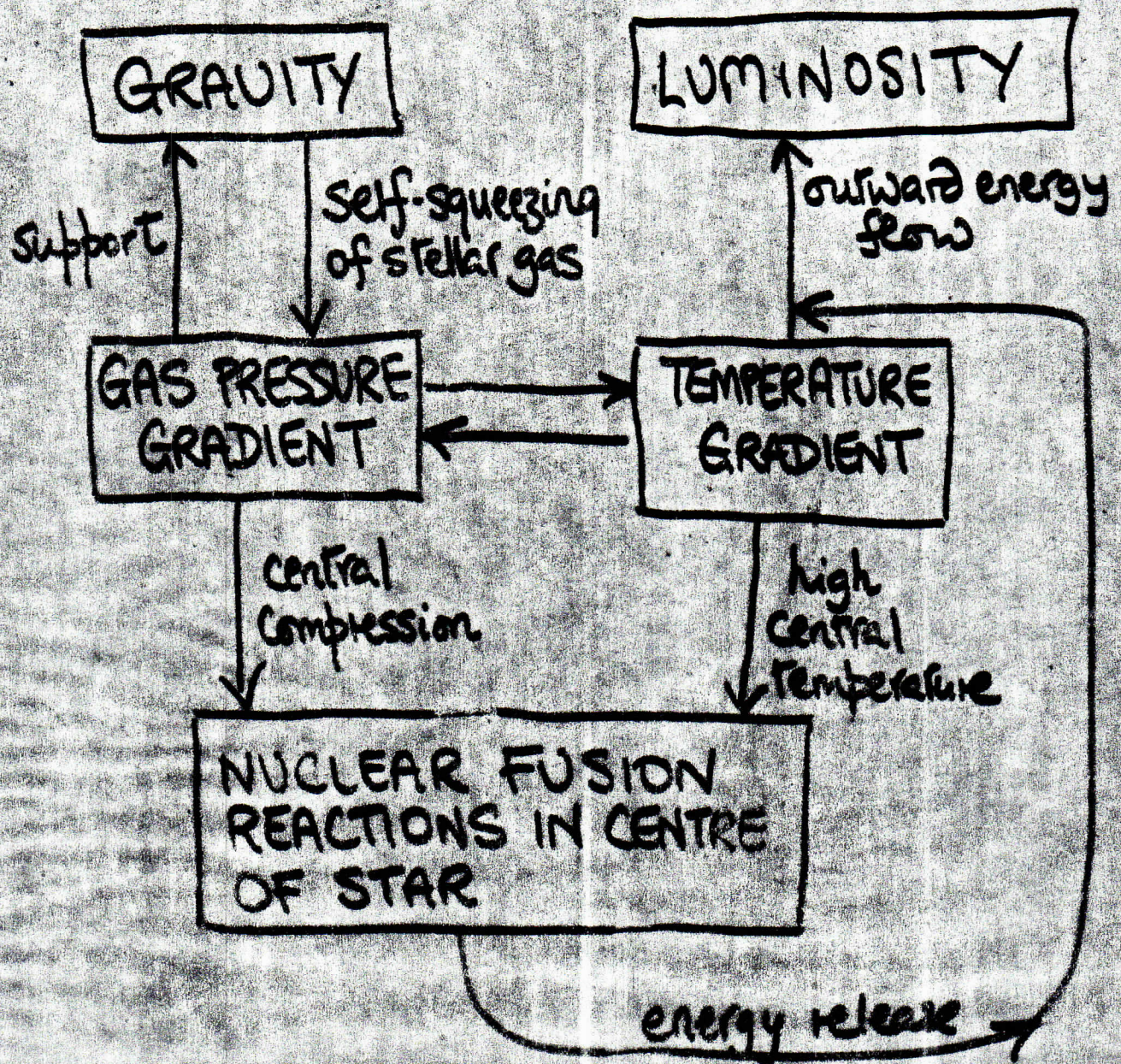
— THEN —

3.



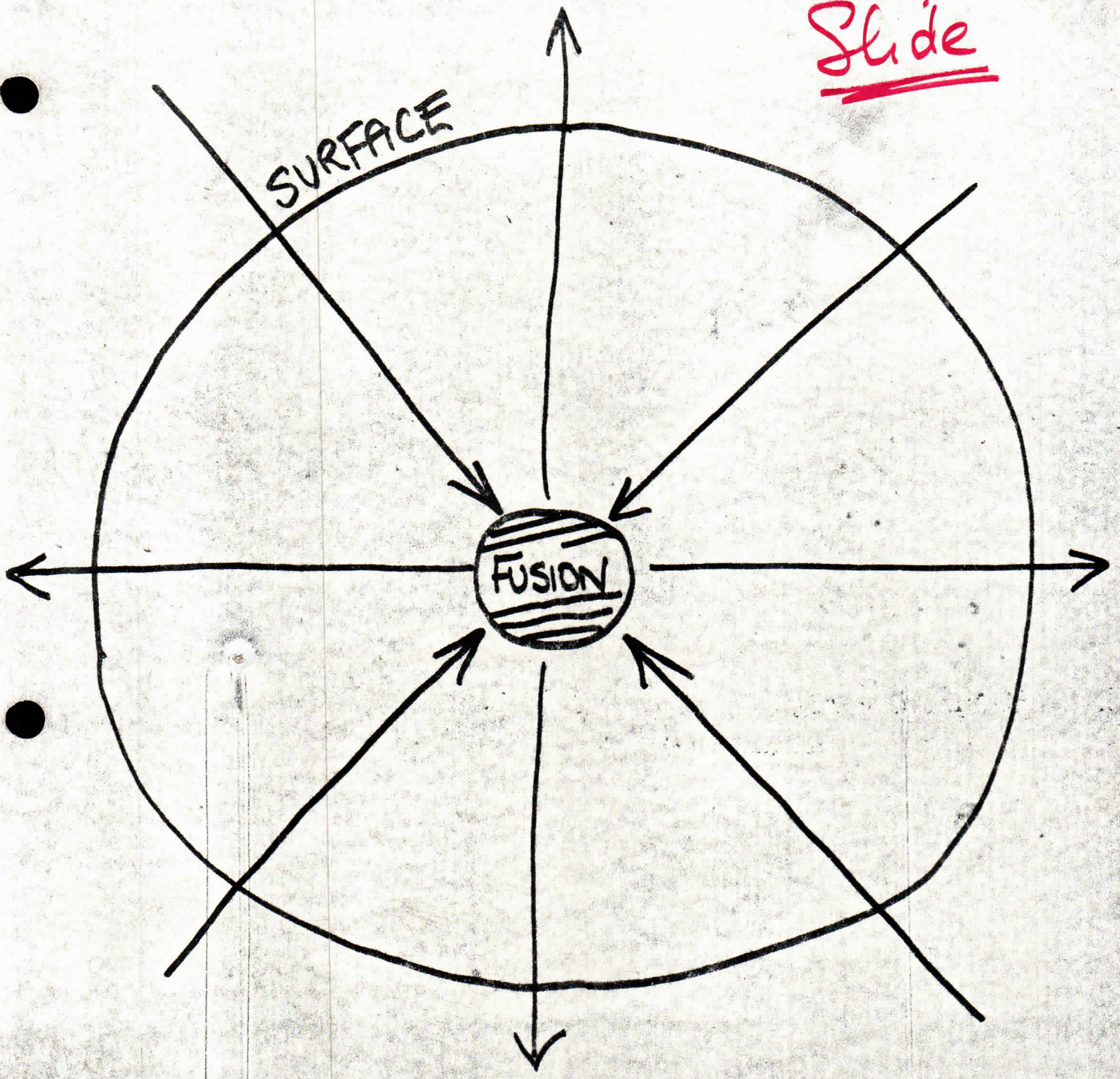
NUCLEAR FUSION BECOMES  
POSSIBLE IN CORE OF STAR.  
ENERGY RADIATED AWAY INTO  
SPACE CAN BE REPLACED BY  
ENERGY GENERATED INSIDE STAR BY  
FUSION. CORE TEMPERATURE CAN  
NOW BE MAINTAINED WITHOUT  
FURTHER COLLAPSE (FOR A WHILE)

# GRAVITY-CONTROLLED EQUILIBRIUM OF STARS



IF FUSION RAN TOO SLOWLY, CENTRE COOLS  
GAS PRESSURE AT CENTRE DECREASES  
SUPPORT DECREASES  
STAR BEGINS TO CONTRACT  
THEN GRAVITATIONAL COLLAPSE REHEATS CENTRE  
AND ACCELERATES FUSION, RESTORING  
EQUILIBRIUM AND SO HALTING COLLAPSE

Slide



Direction of

ENERGY FLOW	] INCREASE
TEMPERATURE	
DENSITY	
GAS PRESSURE	

# 56 HOW TO TEST SOLAR EQUILIBRIUM MODEL

1. INTERIOR CONDITIONS ?
  - Direct probe impossible
2. LIFETIME MEASUREMENT ?
  - Too long to wait
3. CHEMICAL EVOLUTION ?
  - Helium increase in core, not on surface  
Outer layers are "cold shell" of the "nuclear reactor", do not change themselves.
4. VARIATION OF PARAMETERS (EXPERIMENT)  
(Standard method of experimental science).
  - Cannot "fiddle with" parameters of Sun.

BUT CAN OBSERVE PROPERTIES OF OTHER SYSTEMS THAT MIGHT BE BALANCED BY SIMILAR PROCESSES, ONLY DIFFERENT MASS, RADIUS, TEMPERATURE, etc.

- i.e. THE OTHER STARS