

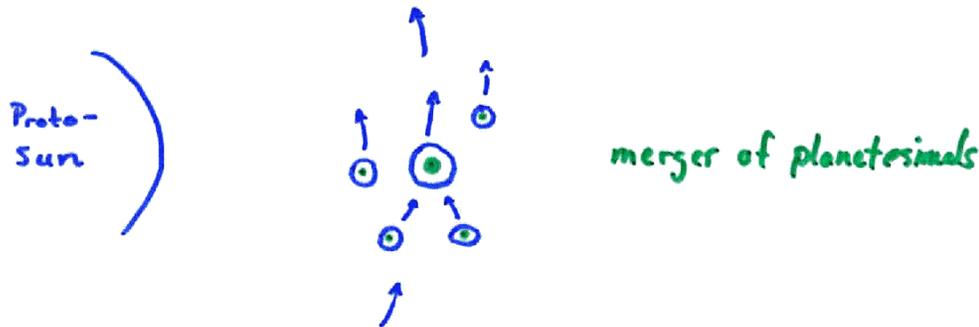
COMPOSITION OF THE CORE

CORE FORMATIONS

- not a single event
- probably formed as the Earth accreted

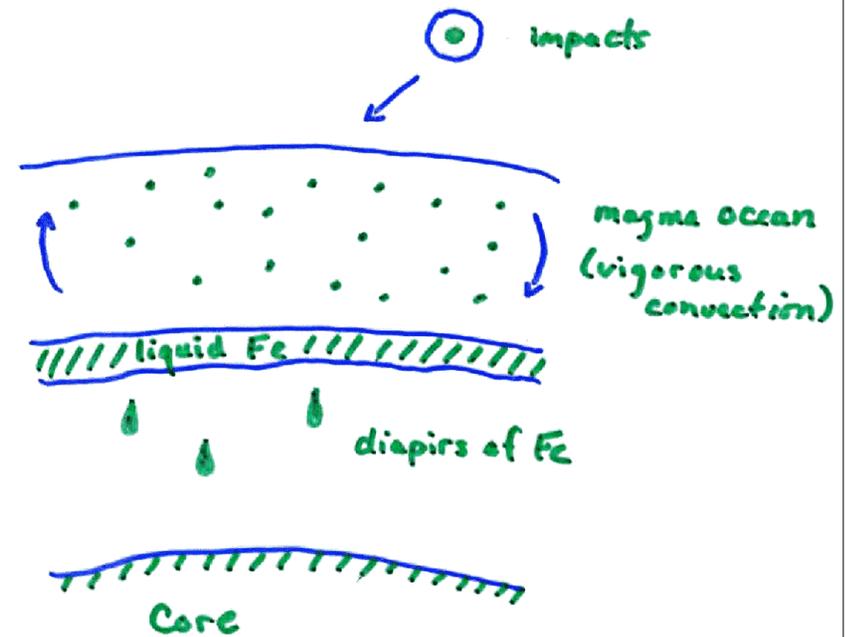
Stages of Planetary Growth

1. Runaway growth - km-size planetesimals to Moon-size bodies in 10^6 years



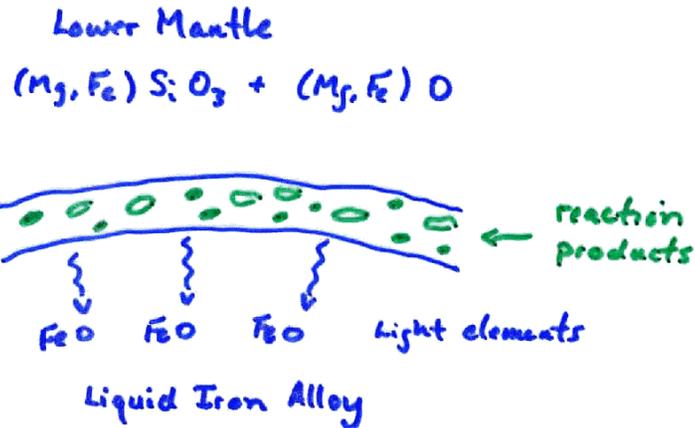
composition determined by low-pressure equilibrium

2. Planetary Growth - accumulation of Moon-size bodies into terrestrial planets



- equilibration of droplets in magma ocean
- liquid Fe becomes more isolated as magma ocean freezes

3. Other: Core-Mantle Interactions



→ gradual addition (or loss) of elements to (from) the core over geological time

Timing of Core Formation

constraints based on radiogenic isotopes



decay products partition into core

Hf-W System

i) core forms late in earth history (after Hf is extinct)

$$\left(\frac{^{182}W}{^{184}W} \right)_{\text{mantle}} \approx \left(\frac{^{182}W}{^{184}W} \right)_{\text{chondrite}}$$

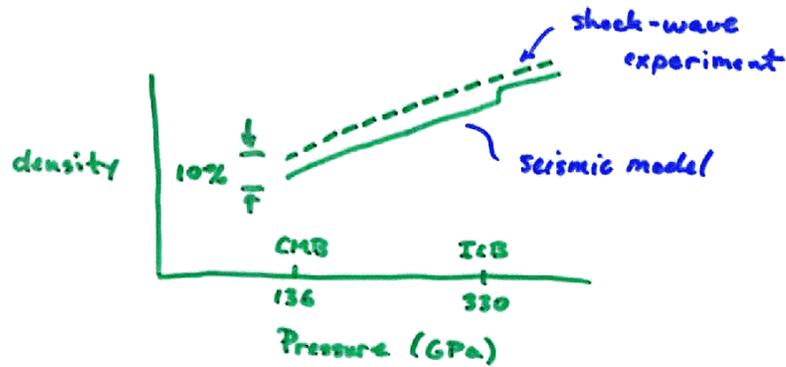
ii) core form early (before extinction)

$$\left(\frac{^{182}W}{^{184}W} \right)_{\text{mantle}} > \left(\frac{^{182}W}{^{184}W} \right)_{\text{chondrite}}$$

• 20 ppm enrichment in mantle

AGE CONSTRAINT $\tau < 30 \text{ Myr}$

Observational Constraints



Interpretation: light elements alloyed with Fe

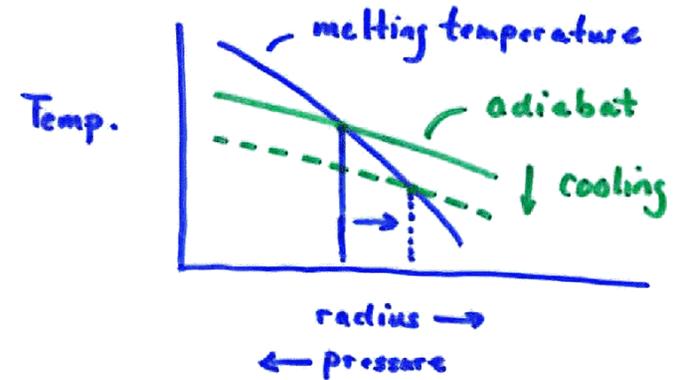
Candidates: H, C, O, S, Si

"An uncertain mixture of all elements"
Birch, 1952

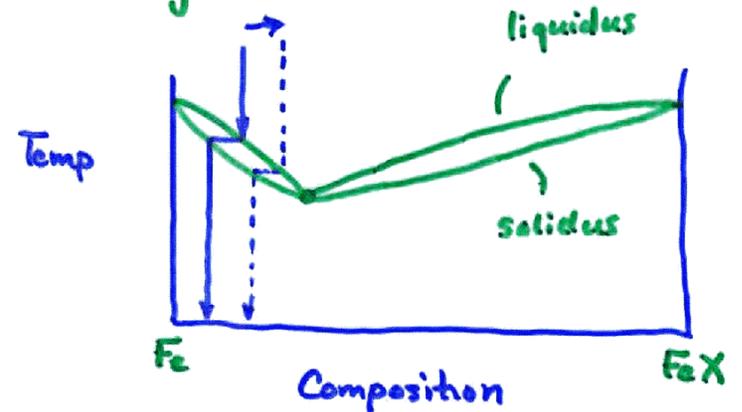
Does Composition Matter?

1. melting temperature
2. core-mantle reactions?
3. dynamics ($\Delta\rho$ due to composition)

Origin of Inner Core



Phase Diagram



composition of the liquid core evolves

Heat Sources

key heat-producing elements in the Earth

→ U, Th, ^{40}K

Are these elements present in the core?

1. U ; Th (conventional wisdom)

- strongly partition into silicates during core formation

∴ No U or Th!

Can we rule out their incorporation into core?

"Consider the following"

⋮

Putting U and Th into the core may account for "missing" heat sources.

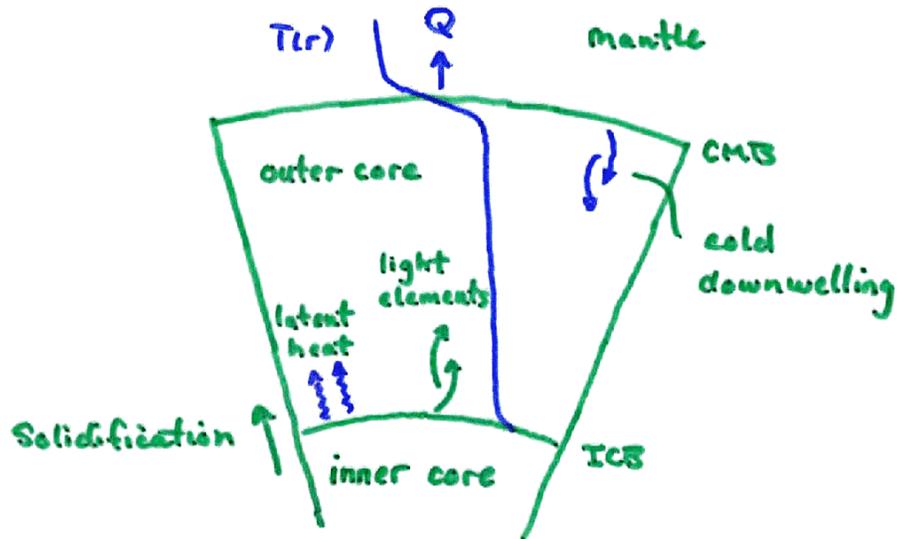
2) Potassium ^{40}K

- potassium may become more soluble at high P
- potassium is less abundant in the mantle relative to chondrites. Either
 - loss of volatiles during accretion
 - sequestered into the core

Experiments - suggest that some K may enter the core. The amount may not be sufficient

→ Too much is also bad!

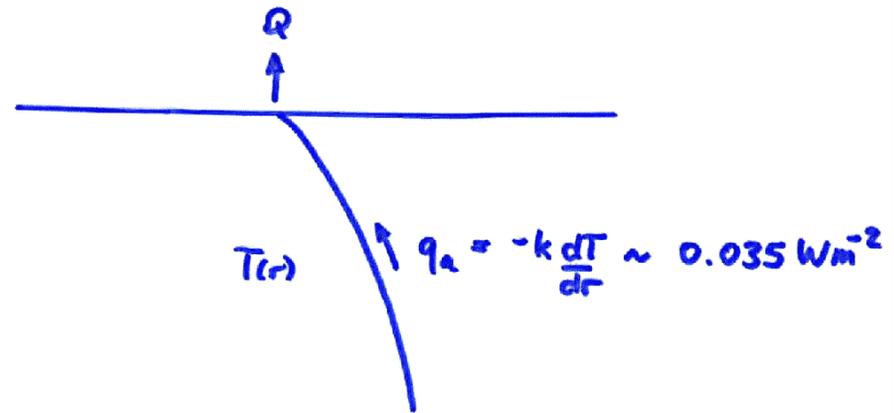
Dynamics of the Core



- cooling depends on $Q - Q_R$
 \uparrow radioactivity
- growth of inner core produces thermal & compositional buoyancy

Physical Properties

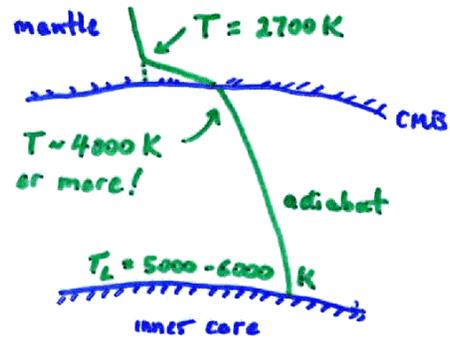
1. viscosity $\sim 0.01 \text{ Pa}\cdot\text{s}$
 \rightarrow typical fluid velocity $\sim 10^{-4} \text{ m s}^{-1}$
 \rightarrow overturn time ~ 1000 years!
2. thermal conductivity $\sim 50 \text{ W K}^{-1} \text{ m}^{-1}$
 \rightarrow a lot of heat conducted down adiabat



$$\text{net heat flow } Q_a = \int_{\text{CMB}} q \cdot dS = 5 \text{ to } 6 \text{ TW}$$

\rightarrow This may be comparable to Q

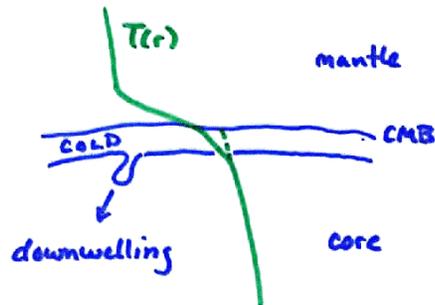
Estimates of Q



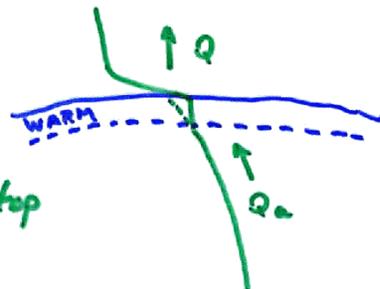
Heat Flow $q = \frac{k\Delta T}{\delta} \sim 6 \text{ to } 12 \text{ TW}$

Consequences

1. $Q > Q_a$

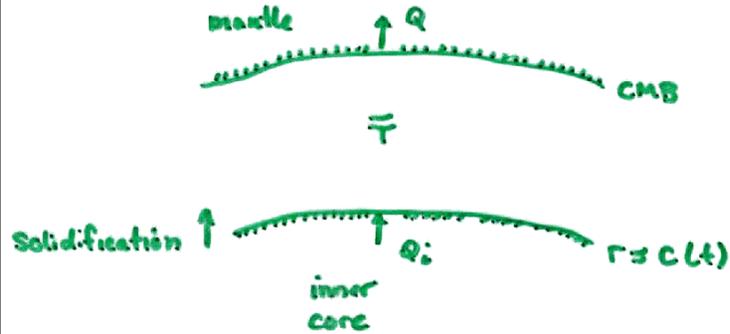


2. $Q < Q_a$



heat accumulates at the top of the core

Growth of Inner Core

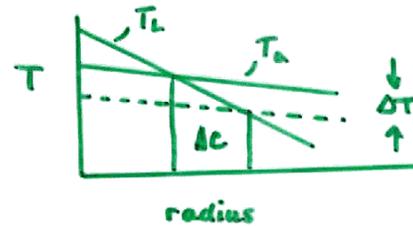


Heat Budget

$$\rho C_p \frac{d\bar{T}}{dt} \times \text{Volume} = -Q + Q_R + Q_i + 4\pi c^2 (L+G) \frac{dc}{dt}$$

(latent heat + gravitational energy)

How does ΔT relate to Δc ?

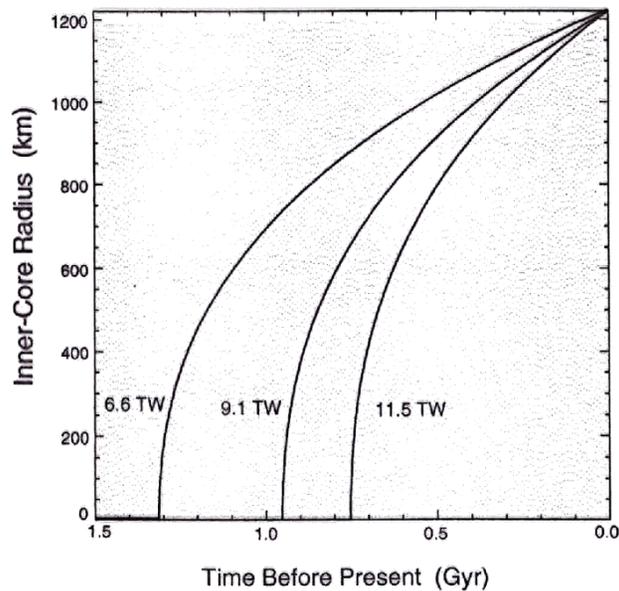


$$\Delta T = \left(\frac{\partial T_L}{\partial r} - \frac{\partial T_a}{\partial r} \right) \Delta c$$

Substitute into heat budget

$$M [2c + 3(L+G)c^2] \frac{dc}{dt} = Q - Q_R$$

Growth of Inner Core



Conclusions

With typical values of Q and $Q_R = 0$

- rapid inner-core growth
- hot early temperatures

Solutions

- add radioactive heat sources $Q_R \neq 0$
- lower heat flow Q
→ how do we reconcile with estimates of \dot{T}



radioactive heat sources
in D''

Limits on Q

Carnot Efficiency

$$\Phi = (\epsilon_T + \epsilon_c) Q$$

↑ Dissipation
(dynamo
power)

efficiencies (thermal &
compositional)

Present-day Estimates $\epsilon_T \sim 0.07$

$\epsilon_c \sim 0.14$

→ vary with time (e.g. inner-core radius)

Dynamo Power $\Phi = 0.1$ to 1 TW

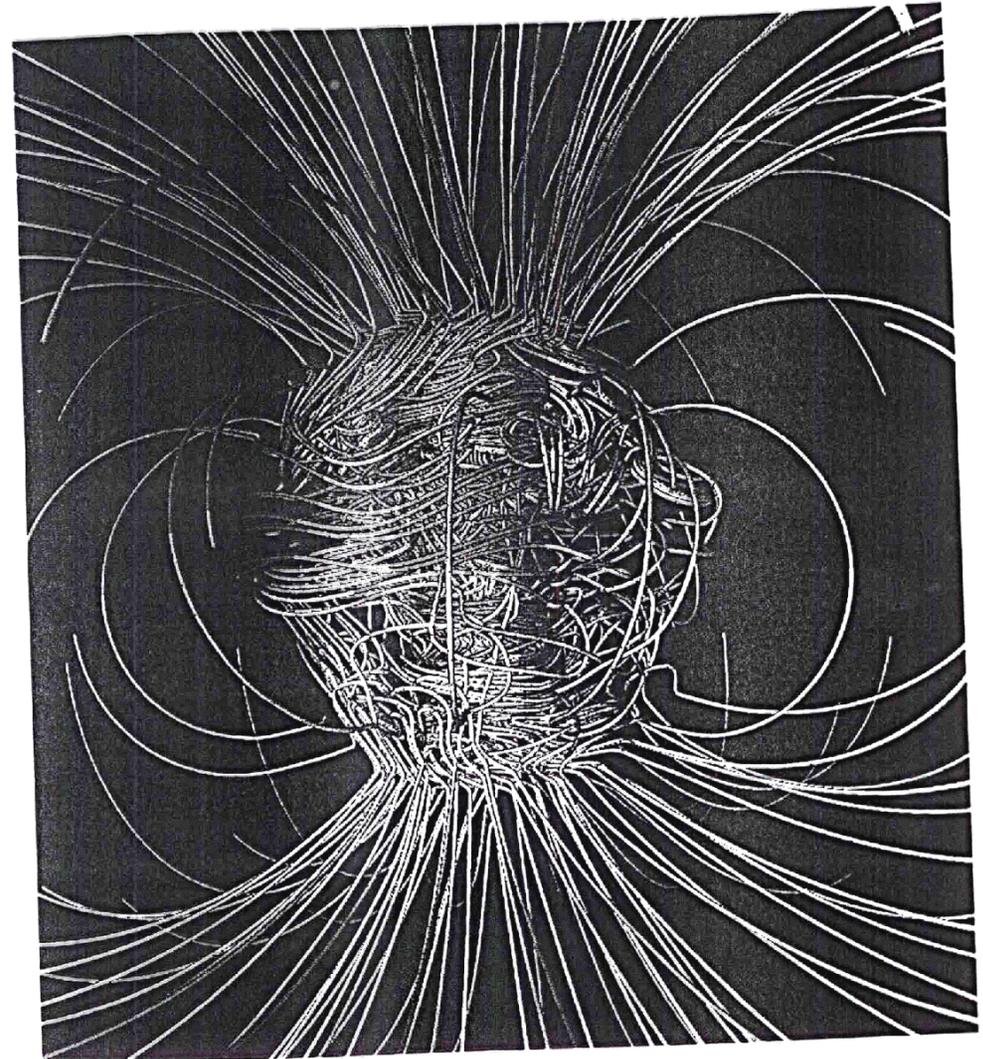


Fig. 2

Power Requirements for the Geodynamo

