

Astro 210
Lecture 30
November 5, 2010

Announcements

- HW 8 due now
 - HW 9 available, due in class next Friday
- Solar Observing** raindate: Monday, 10am-2pm
▷ schedule, report form online

Last time: the source of solar power

Q: how is the Sun different from a cup of coffee?

Q: what is the source of solar power?

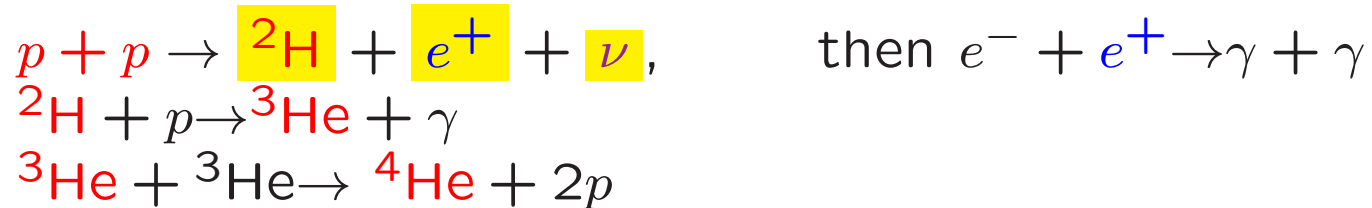
Q: what are the inputs, outputs from the sun's burning reactions?

Hydrogen Burning in the Sun

The Sun is a mass of incandescent gas // a gigantic nuclear furnace
Where hydrogen is burned into helium, // at temperatures of millions of degrees

– Lou Singer and Hy Zaret, 1959; cover: They Might Be Giants 1993

“pp” Chain

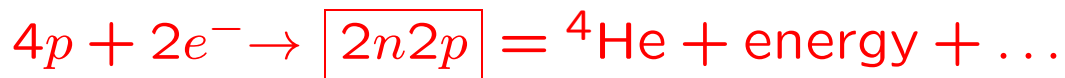


where:

- deuterium ${}^2\text{H} = \boxed{np}$ Q: what's that?
- e^+ “positron” Q: what's that?
- ν “neutrino” Q: what's that?

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Net effect:



Fusion Energy

Where does the energy come from? **mass!**

www: Big Al

www: scale cartoon

Einstein: $\boxed{\varepsilon = mc^2}$

Observed fact: $m(^4\text{He}_{\text{atom}}) < m(4p + 2e)$! whole < parts!

Do the math:

$$m(4p + 2e) = 6.694 \times 10^{-27} \text{ kg} \quad (1)$$

$$- m(^4\text{He}) = 6.644 \times 10^{-27} \text{ kg} \quad (2)$$

$$= \Delta m = 5 \times 10^{-29} \text{ kg} \quad (3)$$

ω fusion → mass reduction!

→ rest mass decrease → energy release!

in each reaction mass \rightarrow energy (kinetic, photons)

$$Q = \Delta\varepsilon = \Delta mc^2 = 4.5 \times 10^{-12} \text{ Joules}$$

for **each** $4p \rightarrow {}^4\text{He}$ fusion

Estimate fusion energy supply:

$$E_{\text{fuse}} = \frac{\# \text{ nuclei in Sun}}{4 \text{ nuclei/fusion}} \times Q \sim 1.3 \times 10^{45} \text{ Joules} \quad (4)$$

Lasts for

$$\tau_{\text{fuse}} = E_{\text{fuse}}/L = 3 \times 10^{18} \text{ sec} = 100 \text{ billion years!}$$

Vote your conscience!

This is a crude estimate of the solar fusion lifespan—but how?

4

A

this is an *over*estimate of the lifespan

B

this is an *under*estimate of the lifespan

Solar Life Expectancy

Overestimated fuel available for fusion:

→ only fuse at high T , ρ

→ core of Sun

true lifetime: $\tau \sim 1 \times 10^{10}$ yr = 10 billion yrs

→ Sun is middle aged

will last another ~ 5 billion yrs

Q: how test that sun is nuke powered?

How Do We Know?

By the 1930's we knew that the Sun is nuclear powered

www: Nobel Prize: Hans Bethe

Q: how could we be so sure?

Can we get even more direct confirmation?

*Q: is another way to confirms the Sun is a nuclear reactor? A
"smoking gun" signature?*

The Evidence: Solar Neutrinos

If the Sun takes $4p \rightarrow {}^4\text{He} = \boxed{2p2n}$

then it *must* convert $2p \rightarrow 2n$

→ *must* produce neutrinos!

in fact: most made via $pp \rightarrow de^+ \nu$

The Sun radiates neutrinos as well as photons!

...we are bathed in solar “neutrinoshine”

Moreover:

- since ν are weakly interacting
they come directly from the solar core
→ messengers from the center of the Sun!
- but luckily, *weakly* interacting \neq *non*-interacting
⇒ solar neutrinos are potentially observable!
- clever experiments can try to “catch” them

In Search of Solar Neutrinos

experiments have been built to “see” solar neutrinos by observing rare cases of ν interactions with atoms
all use huge underground detectors

Q: why huge? why underground?

Two types:

1. “radiochemical” – vats of fluid

see element change due to ν

ex: chlorine fluid $\nu + {}^{37}\text{Cl} \rightarrow {}^{37}\text{Ar} + e^-$

collect Ar atoms (radioactive!)

www: Cl expt

2. “scattering” – vats of ultrapure water

see light pulses from

high-energy e^- scattered by ν s

∞

www: SNO ball

www: Super-K Sun image

Upshot:

- ★ All experiments detect solar ν s!
- ★ Amount (flux) is just as predicted

Q: what fundamental fact(s) is/are confirmed?

Solar Neutrino Results

- I. proof that Sun powered by nuke fusion
- II. ν s give view into solar core
- III. these are ν telescopes!

A new window on the Universe:

Nobel Prize 2002!

Poetry reading: John Updike, "Cosmic Gall"

The Stars as Suns

We've proved that that Sun is nuclear reactor
but (we'll see that) the Sun is a typical star
⇒ **all** stars run by thermonuclear fusion

The Night sky, the Universe lit up ultimately by nuclear power

How do we know Sun is typical?
Compare!

www: big picture cartoon