Astronomy 100
Tuesday, Thursday 2:30 - 3:45 pm

Tom Burbine
tburbine@mtholyoke.edu

www.xanga.com/astronomy100
Two thing about the tests and the final
What was easiest question on the 2\textsuperscript{nd} exam?
Was this the easiest question on 2nd exam?

- Who was the first to propose the formula $E=mc^2$ for converting matter into energy?
  - A) Isaac Newton
  - B) Albert Einstein
  - C) Stephen Hawking
  - D) Richard Feynman
  - E) Johannes Kepler
E = mc²

• m is mass in kilograms
• c is speed of light in meters/s
• So E is in joules
• very small amounts of mass may be converted into a very large amount of energy and
Who came up with it?
How many people got this question wrong?
33
about 10% of the class
What was the easiest question on the 1st exam?
Was this the easiest question on 1st exam?

- What galaxy do we reside in?
- A) Andromeda
- B) Milky Way
- C) ecliptic
- D) Sirius
- E) Ursa Major
Milky Way Galaxy

- Milky Way is 100,000 light years in diameter
- There are ~100 billion stars in the Milky Way
How many people got this question wrong?
12
about 4% of the class
Finals

• The Final exams will be questions from the first 4 exams with the numbers changed
1st Homework question (March 24) (beginning of class)

• I want you to detail the hydrogen fusion reaction (Steps 1 through 3) with words (written by hand) and pictures
• What is the solar neutrino problem?
• How was the Homestake Gold Mine used to detect neutrinos?
2 protons fuse together
Forms proton and neutron (deuterium- Hydrogen isotope)
Positron given off and destroyed by colliding with electron
2 gamma rays given off
Neutrino given off

Figure 15.7
Figure 15.7

Proton fuses with deuterium
Forms Helium-3
Gamma ray given off
Collision of two Helium-3 nucleus
Produces Helium-4 nucleus and 2 protons

Steps 1 and 2 must occur twice

Figure 15.7
Neutrinos

- Neutrinos – almost massless particles
- No charge
- It takes a neutrino 2 seconds to exit the Sun
What is the solar neutrino problem?

• A) More neutrinos appear to be produced from the Sun than expected from models
• B) Less neutrinos appear to be produced from the Sun than expected from models
• C) Neutrinos are dangerous to humans
• D) Neutrinos interfere with the fusion of hydrogen into helium
• E) Neutrinos turn helium into Lithium
What is the solar neutrino problem?

A) More neutrinos appear to be produced from the Sun than expected from models
B) Less neutrinos appear to be produced from the Sun than expected from models
C) Neutrinos are dangerous to humans
D) Neutrinos interfere with the fusion of hydrogen into helium
E) Neutrinos turn Helium into Lithium
How was the Homestake Gold Mine used to detect neutrinos?

• A 400,000 liter vat of chlorine-containing cleaning fluid was placed in the Homestake gold mine
• Every so often Chlorine would capture a neutrino and turn into radioactive argon
• Modelers predict 1 reaction per day
• Experiments found 1 reaction every 3 days
2nd HW question (due March 24th) (beginning of class)

• How much longer will it take the Sun to use up all its “fuel”?
• When the Sun uses up its fuel it will start expanding, which will be bad for people living on Earth
• I want an answer in years
• Show your work
I know this HW was difficult

- This homework is to show how you can make rough estimates
- Know 10% of sun can undergo fusion
- Know 0.7% mass during fusion reaction is turned into energy
- Determine lifetime of Sun
So

- You get 1 point for turning it in
- You get 1 point for getting right answer
Things you need to know

• Energy source for sun is four hydrogen atoms combining to produce one helium atom
• about 0.7% of the original mass is turned into energy during this process
• 10% of the Sun’s mass is hot enough to undergo fusion
• Mass of the Sun = $2 \times 10^{30}$ kg
And

- Total lifetime = \( \text{(energy available)} \) (rate \([\text{energy/time}]\) at which sun emits energy)

- rate \([\text{energy/time}]\) at which the Sun emits energy is equal to \(3.8 \times 10^{26}\) Watts (Joules/second)
And

- Time left = Lifetime – current age
- Current age = ~5 billion years
Calculation

- Mass of the Sun that is turned into energy
  \[ m = 2 \times 10^{30} \text{ kg} \times 10\% \times 0.7\% \]
  \[ m = 1.4 \times 10^{27} \text{ kg} \]
  - Sun can be turned into energy
  - \[ E = mc^2 \]
  \[ E = 1.4 \times 10^{27} \text{ kg} \times 9 \times 10^{16} \text{ m}^2/\text{s}^2 \]
  \[ E = 1.26 \times 10^{44} \text{ Joules} \]
Calculation

• Lifetime = $1.26 \times 10^{44}$ Joules/$3.8 \times 10^{26}$ Joules/second

• Lifetime = $3.3 \times 10^{17}$ seconds

• Lifetime = $1.05 \times 10^{10}$ years

• Time left = 10.5 billion years – 5 billion years

• Time left = 5.5 billion years
Fusion

• The rate of nuclear fusion is a function of temperature
• Hotter temperature – higher fusion rate
• Lower temperature – lower fusion rate
• If the Sun gets hotter or colder, it may not be good for life on Earth
What is happening to the amount of Helium in the Sun?

• A) Its increasing
• B) its decreasing
• C) Its staying the same
What is happening to the amount of Helium in the Sun?

- A) Its increasing
- B) its decreasing
- C) Its staying the same
HW (Chapter 16)

- I want you to draw me a Hertzsprung-Russell Diagram
- Label the axes
- Label the regions with different types of stars
- O, B A, F, G, K, M
- Tell me the phrase people use to remember the order
So how does the Sun stay relatively constant in Luminosity (power output)
Figure 15.8

- Large decrease in rate of fusion
- Slight decrease in core temperature
- Slight rise in core temperature
- Large rise in rate of fusion

Solar Thermostat: Gravitational Equilibrium

Because the energy supply is diminished, gravity starts to overcome thermal pressure.

Gravity compresses the core, heats it up, and restores fusion rate to normal value.

Increased energy output enables thermal pressure to overcome gravity.

Increased thermal pressure causes the core to expand and then cool, which restores fusion rate to normal value.

© 2005 Pearson Education, Inc., publishing as Addison Wesley
Figure 15.4
Parts of Sun

Core

- Core – 15 million Kelvin – where fusion occurs
Figure 15.4
Radiation zone

- Radiation zone – region where energy is transported primarily by radiative diffusion
- Radiative diffusion is the slow, outward migration of photons
Photons emitted from Fusion reactions

- Photons are originally gamma rays
- Tend to lose energy as they bounce around
- Photons emitted by surface tend to be visible photons
- Takes about a million years for the energy produced by fusion to reach the surface
Convection Zone

- Temperature is about 2 million Kelvin
- Photons tend to be absorbed by the solar plasma
- Plasma is a gas of ions and electrons
- Hotter plasma tends to rise
- Cooler plasma tends to sink
Granulation – bubbling pattern due to convection
bright – hot gas, dark – cool gas
Figure 15.10
Photosphere

- Photosphere is the solar surface
- Where photons escape into space
Sunspots

- Sunspots are on the photosphere
- Have temperatures of \( \sim 4,000 \) K
- Photosphere is 5,800 K
Sunspots

• Sunspots are regions of intense magnetic activity
• Charged particles tend to follow magnetic field lines
Figure 15.17

Magnetic fields of sunspots suppress convection and prevent surrounding plasma from sliding sideways into sunspot.
The cycle has a period of approximately 11 years, but the interval between maxima can be as short as 7 years and as long as 15 years.
Maunder Minimum

- Between 1645 and 1715, the sunspot activity virtually stopped
- Identified by E. W. Maunder from historical sunspot records
Figure 15.4
Atmosphere of the Sun

• Chromosphere – above the photosphere and below the corona
• Temperature is about 10,000 Kelvin
• Most of the Sun’s ultraviolet light is emitted from this region
See Corona during eclipse
Atmosphere of the Sun

- Corona – tenuous uppermost layer of the Sun’s atmosphere
- Temperature is about 1 million Kelvin
- Most of the Sun’s X-rays are emitted from this region
Corona

- Extends millions of kilometers into space
- Why it's so hot is unknown
- Sun's corona is constantly being lost as solar wind.
PRS for making it through class
Questions