Session 42
Review
The Universe, and its Dark Side
Dec 9, 2011

Email: ph116@u.washington.edu
Announcements

• Final exam: Monday 12/12, 2:30-4:20 pm
• Same length/format as previous exams (but you can have 2 hrs)
• Kyle Armour is away this week; see TAs in study center
• JW will have extra office hours Thu-Fri this week:
  • 12:45-1:15pm before class,
  • 2:30-3pm after class  (my office B303 PAB, or B305 conf room next door)

• Kyle will have an office hour Monday, 11:30, B442
PHYS 248: A new general-education physics course you might be interested in...

Energy Future
The Science, Economic Opportunity, and Climatic Impact of Sustainable Energy

PHYS248 Winter 2011 (SLN 17583, 5 credits, NW credit)
Monday & Wednesday 3:30-5:30PM in Physics-Astronomy Auditorium PAA118

Instructor: Prof. G. Seidler efuture@uw.edu

Course Content
PHYS248, Special Topics, in Winter 2012 will be the second offering of a (soon to be) permanent 200-level course on Sustainable Energy. We will survey many different aspects of the looming global energy crisis from a technical and social perspective. The only prerequisites for the class are a good grasp of basic mathematics (algebra, only -- no calculus) and an enthusiasm to learn about a core issue for the future of almost every aspect of our day-to-day lives.
Lecture Schedule
(to end of term)

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Done!
1) Hydrogen atoms can emit four lines with visible colors from red to violet. These four visible lines emitted by hydrogen atoms are produced by electrons
A) that start in the $n = 2$ level.
B) that end up in the $n = 2$ level.
C) that end up in the $n = 3$ level.
D) that end up in the ground state.
E) that start in the ground state.
Answer:  B
The Balmer series is the one that has lines in the visible range, and it is due to transitions into $n=2$

2) According to the quantum mechanical model of the hydrogen atom, if the orbital angular momentum quantum number is $\ell$, there will be how many permitted magnetic quantum numbers?
A) $\ell/2$
B) $2\ell$
C) $2\ell + 1$
D) $2\ell - 1$
E) $3\ell$
Answer:  C
Allowed values of $m$ range from $-\ell$ through 0 to $+\ell$, so there are $2\ell + 1$

3) Which one of the following is the correct electronic configuration for the ground state of carbon?
A) $1s^2 2s^2 2p^2$
B) $1s^1 2p^1$
C) $1s^1 2s^2 2p^1$
D) $1s^1 2s^1 2p^1$
E) $1s^2 2s^2 2p^4$
Answer:  A
For carbon, $Z=6$. Only (A) has 6 electrons! It also correctly shows all lowest states filled
4) An electron in the hydrogen atom has a deBroglie wavelength of $1.99 \times 10^{-9} \text{ m}$. To what state of the hydrogen atom does this electron belong?

A) $n = 1$
B) $n = 3$
C) $n = 4$
D) $n = 6$
E) $n = 8$

Answer: D

Bohr radius for this $n$ gives circumference = integer number of deBroglie wavelengths.

5) In beta minus decay, the number of neutrons in the nucleus is

A) decreased by 1.
B) decreased by 2.
C) increased by 1.
D) increased by 2.
E) remains unchanged.

Answer: A

Beta decay means a neutron turns into a proton, so nucleus loses 1 negative charge unit = gets one unit more positive: it gains 1 in Z, but has the same A.

6) Polonium-216 ($Z=84$) decays to lead-212 ($Z=82$) by emitting what kind of nuclear radiation?

A) Alpha
B) Beta minus
C) Beta plus
D) Gamma
E) X-rays.

Answer: A

Po loses 4 units of A and 2 protons, so this must be alpha decay.
7) The symbol for a certain isotope of polonium is . How many neutrons are there in the nucleus of this isotope?
   A) 84  
   B) 130  
   C) 214  
   D) 298  
   E) 314 
   Answer: B 
   \[ N = A - Z = 214 - 84 = 130 \]

8) The number of radioactive nuclei in a particular sample decreases to one-eighth of its original number in 9 days. What is the half-life of these nuclei?
   A) 9/8 days  
   B) 2 days  
   C) 3 days  
   D) 8 days  
   E) 10 days 
   Answer: C 
You can do it the hard way:

\[ T_{1/2} = \frac{\ln 2}{\lambda} \Rightarrow \lambda = \frac{0.693}{T_{1/2}} \text{ and } \frac{N}{N_0} = e^{-\lambda t} = \exp \left( -\frac{0.693 t}{T_{1/2}} \right) \Rightarrow \frac{1}{8} = \exp \left( -0.693 \left[ \frac{9 \text{ days}}{T_{1/2}} \right] \right) \]

Or you can find it the easy way:

1/8 = (1/2)(1/2)(1/2) so time to reach 1/8 = three half-lives: 9 d = 3 \( T_{1/2} \)
9) Fermium-253 has a half-life of 3.00 days. A sample of fermium has $3.88 \times 10^6$ nuclei. What is the initial activity (ie, at $t=0$ when this number of nuclei remain) of this sample?

A) 10.4 Bq  
B) 10.4 Ci  
C) 12.9 Bq  
D) 12.9 Ci  

Answer: A

\[
\lambda = \frac{\ln 2}{T_{1/2}} = \frac{\ln 2}{3d} = \frac{0.693}{259,200 \text{ sec}} = 2.67 \times 10^{-6} \text{s}^{-1}
\]

\[
N = \frac{R}{\lambda} \Rightarrow R_0 = N_0 \lambda = \left(3.88 \times 10^6\right) \times 2.67 \times 10^{-6} \text{s}^{-1} = 10.37 \text{s}^{-1}
\]

1 Bq = 1 s$^{-1}$ $\Rightarrow R_0 = 10.37$ Bq (note: 1 Ci = $3.7 \times 10^{10}$ s$^{-1}$, so $R_0 = 2.8 \times 10^{-9}$ Ci)

10) If a reactor produces an average power of 1000 MW for a year, how much $^{235}\text{U}$ is used up assuming 200 MeV are released per fission? Recall, Avogadro’s number = $6.02 \times 10^{23}$ atoms per mole, where 1 mole = $A$ grams of element with atomic mass $A$.

A) 0.35 kg  
B) 1.75 kg  
C) 384 kg  
D) $1.1 \times 10^8$ kg  
E) $3.3 \times 10^8$ kg  

Answer: C

$1000 \text{ MW} = 10^9 \text{ J/s}, 1 \text{ y} = 3.15 \times 10^7 \text{ s}, 1000 \text{ MW} \cdot \text{y} = 3.15 \times 10^{16} \text{ J}$

$200 \text{ MeV} = 200 \left(1.602 \times 10^{-13} \text{ J}/\text{MeV}\right) = 3.2 \times 10^{-11} \text{ J}$

$N = 3.15 \times 10^{16} \text{ J} / 3.2 \times 10^{-11} \text{ J} = 9.83 \times 10^{26} \text{ nuclei}$

$9.83 \times 10^{26} / 6.02 \times 10^{23} \text{ atoms/mole} = 1633.13 \text{ moles of } \text{U}$

$= 1633.13 \text{ moles} \cdot (0.235 \text{ kg/mol}) = 383.8 \text{ kg}$
11) Two deuterium nuclei, \(^2\text{H}\), fuse to produce a tritium nucleus, \(^3\text{H}\), and a hydrogen nucleus. A neutral deuterium atom has a mass of 2.014102 u (atomic mass units); a neutral tritium atom has a mass of 3.016050 u; a neutral hydrogen atom has a mass of 1.007825 u; a neutron has a mass of 1.008665 u; and a proton has a mass of 1.007277 u. How much energy is released in the process?

1 u = 931.494 MeV/c\(^2\).

A) 3.03 MeV
B) 3.53 MeV
C) 4.03 MeV
D) 4.53 MeV
E) 6.58 MeV

Answer: C

Atomic mass includes electrons.

Deuterium nucleus = \((2.014102 \text{ u})(931.494 \text{ MeV/c}^2 / \text{u}) - \text{electron mass}\)

Initial mass = \(2((1876.124 \text{ MeV/c}^2) - (0.511 \text{MeV/c}^2)) = 3751.226 \text{ MeV/c}^2\)

Tritium nucleus = \((3.016050 \text{ u})(931.494 \text{ MeV/c}^2 / \text{u}) - \text{electron mass}\)

Final mass = \((2809.432 \text{ MeV/c}^2 - (0.511 \text{MeV/c}^2)) + ((1.007277 \text{ u})(931.494 \text{ MeV/c}^2)) = 3747.193 \text{ MeV/c}^2\)

Difference = mass that was converted into energy = 4.03 MeV/c\(^2\)

\[E = (\text{mass loss}) \, c^2 = (4.03 \text{ MeV/c}^2) \, c^2 = 4.03 \text{ MeV}\]
What’s the Nature of the Vacuum?

• What’s going on when there is nothing there?
• Quantum Mechanics tells us the vacuum must be a turmoil of continuous production and annihilation of particle-antiparticle pairs: \(E=mc^2\) in action
  - Uncertainty also says you can violate energy conservation temporarily:
    \[\Delta E \Delta t \sim h\]
    \[\text{[“borrowed” energy] } \times \text{[time of “loan”]} \sim \text{Planck’s constant (very tiny number)}\]

Not “real”: if one of these actually interacts, the energy mortgage has to be paid!

This happens all around us, all the time, in “empty” space.
What impact does this sea of “virtual particles” have on the expansion of the Universe? Is this related to Dark Energy?
GUTs, Strings and TOEs

- Grand Unified Theories (GUTs) try to combine strong and weak forces
- One popular approach: string theory
  - Quarks (for example) could be standing waves on Planck-scale sized “strings”
- Strings may be only part of a Theory of Everything (TOE)
Many versions of string theory require Supersymmetry (SUSY)

SUSY assumes every fermion (quarks, leptons) has a boson partner, and every boson (photons, gluons, W/Z) has a fermion partner: superpartners

In return we get: nice unification of forces, nice candidate for Dark Matter (next topic)

But remember: No direct evidence yet for SUSY!

"Since the superpartners of the Standard Model particles have not been observed, supersymmetry, if it exists, must be a broken symmetry, allowing the superparticles to be heavier than the corresponding Standard Model particles."

Many physicists think SUSY has "too many free parameters" and is pursued because it would solve basic physics issues so neatly

- "SUSY must be true – half the predicted particles have been found already!" -Ken Young

If the Higgs boson is observed to have mass ~15 GeV (as LHC is likely to announce next week), it would be consistent with one SUSY version: Minimum SUSY + Standard Model (MSSM)
Quantizing gravity in a TOE?

- Standard Model does not include gravity
- TOEs try to combine quantum particle physics (unified) and quantum gravity

This is where particle physics (physics on the smallest scale) meets cosmology (physics on the biggest scale)...

Now I can let you in on the dark secret:

Oops – we don’t know exactly what 95% of the energy in the Universe represents…
Dark matter and the cosmological constant

- Hadrons and leptons (what we call “matter”) make up less than 5% of the total mass of the Universe needed to make our Standard Model of Cosmology (big bang theory) work out properly
  - We saw evidence of Dark Matter (non-radiating) in galaxies in the 1980s – they do not rotate according to Newtonian physics, as they should!
  - DM cannot be just a lot of dead stars – must be some unknown particle
    - SUSY?

- Astrophysical observations suggest that Universe is not only expanding but the expansion rate is accelerating!
  - Einstein put an acceleration parameter into General Relativity in 1916
    - “Cosmological constant” – needed to preserve a static universe
    - When he found out about expanding universe (1920s), he called it his “worst blunder”
    - We put it back in 1998!! Now it’s “dark energy” (don’t know what it is)

- The Dark Side (dark matter, and dark energy) are focus of intense study now! Here at UW, Prof. Les Rosenberg leads a DM search
Geometry, age, and fate of the Universe

- Will Universe's expansion be stopped by gravity of its contents? Geometry of space is determined by its mass density:
  - "Big Crunch" ($\Omega > 1$) = expansion slows to 0 and then reverses: Universe eventually collapses back into a point
    - Spherical geometry
      - parallel lines always meet
      - sum of angles of triangle > 180°
  - "Big Freeze" ($\Omega < 1$) = Expansion rate reaches a minimum and stays constant: Universe cools down forever
    - Hyperbolic (saddle-shaped) geometry
      - Sum of angles < 180°
  - "Critical density" ($\Omega = 1.0$): expansion slows but never stops
    - Flat, 'Euclidean' geometry
      - parallel lines never meet
      - angles of triangle add up to 180°
Supernovae tell us expansion is *accelerating*

Distant supernovae appear farther away than they “should be”. (“Should be” represents the case where the Hubble expansion is *linear*, or *unaccelerated*. That is, redshift is *strictly proportional* to distance.)
Putting It All Together

- CMB observations told us:
  - Universe is flat
  - parallel lines remain parallel forever
- Supernova studies tell us:
  - Universe is accelerating!
  - Cosmological Constant $\Lambda$ exists
  - Vacuum repulsion energy!

Overlap of 2 studies (arrow) gives us best estimate to date for $\Omega_\Lambda$ & $\Omega_M$

- Clustering of galaxies already told us $\Omega_{\text{MATTER}} \approx 0.3$
  - Only 30% of energy content of Universe is in the form of known or hypothesized types of matter
  - So: What is the "dark energy"?
Composition of our Universe

To astronomers, any element above lithium (Z=3) is “heavy”
The Energy* Budget of the Universe

* Remember, matter is a form of Energy: \( E=mc^2 \)
  (more on this later)

\[ \Omega > 1 \text{ Universe ends in big crunch} \]
\[ \Omega = 1 \text{ “Critical” density (flat Universe)} \]
CMB + Supernovae say this is right!
\[ \Omega < 1, \text{ Universe ends in big fizzle} \]

“Dark Energy”, from the Cosmological Constant

“Best estimate” density of all matter in the Universe

Ordinary (“Baryonic”) Matter, at most 5% of critical density

“Dark Matter” = 5/6 of matter in the Universe (new particles)

Stars are less than 1% of critical density

Most gravitating matter is dark (not in the form of shining stars).
Most of this, even, isn’t in a familiar form of particle (not nuclei).
And most of the energy density in Universe isn’t mass at all!
Cosmological 'Conclusions'...

- Universe is *expanding* (we've known this since the 1920's)
- Not enough *matter* to gravitationally arrest the expansion
  - Only about 30% of the necessary total
  - Most of the gravitating matter is in a form as yet unidentified
    - ordinary nuclear matter is ruled out by observations
    - probably some as-yet unknown "new" particle(s)
- Evidence exists that expansion is in fact *accelerating*
  - Remaining 70% of Universe's energy density may be *pushing*
  - Big questions raised by this "dark energy"
    - Current models in fundamental particle physics ("string theories")
      lead to a *quantum gravity* theory: could explain dark energy

Stay tuned!

“Scientists confirmed today that everything we know about the structure of the Universe is wrongedy-wrong-wrong!”

*New Yorker, 7/13/98*
Our Universe could be merely a “vacuum fluctuation”...

- “Cosmic inflation” is needed to make cosmology (our picture of the evolution of the Universe) work - but this concept came from studies of Grand Unified Theories (GUTs) of particle physics
- Our Universe may be just one bubble in a foam of other universes…
- The net energy of the Universe could be zero and our Universe could be just a quantum fluctuation which has not yet returned its net energy!
- Such ideas can be disturbing, even to experts:
  "[George Gamow] casually mentioned that...according to Einstein's equations, a star could be created out of nothing at all, because its negative gravitational [binding] energy precisely cancels out its positive mass energy. "Einstein stopped in his tracks," says Gamow, "and, since we were crossing a street, several cars had to stop to avoid running us down."
  - see http://www.biols.susx.ac.uk/home/John_Gribbin

We've come full circle:

- Physics on the microscopic scale influences the eventual fate of the Universe
- The 20th century saw remarkable progress in increasing our fundamental understanding of Nature, but there remain fundamental open questions

(Just like 100 years ago!)
Unification of Fundamental Forces of Physics

1864 Maxwell

Electricity

Magnetism

Light

Beta-decay

Neutrinos

Protons

Neutrons

Pions, etc.

1971 Weinberg & Salam

Electromagnetism

Electroweak Interaction

Weak Interaction

1965

1973

Strong Interaction

“Standard Model”

1976--

1687 Newton

Universal Gravity

1916 Einstein

General Relativity

1907 Einstein & Minkowski

Spacetime Geom.

pre-20th c. 20th c.

Earth Gravity

Celestial Mech.

1907 Einstein & Minkowski

1916 Einstein

General Relativity

2012?

String theory? Supersymmetry? GUTs?