Chemistry Connections
(CHEM 106)

- *Chemistry ⇆ STEM*
- *Linked by the Scientific Method*

Chemistry focuses on the study of

- *Energy & Matter:*
  Classification, Behavior & Properties

All Science, Technology & Engineering involves:

- *Observations & Measurements:*
  (Qualitative & Quantitative using international [SI] & related metric units)

Chemistry Connections
(CHEM 106)

STEM Mathematics is the collection of tools used to analyze observations, test results and predict outcomes. It has many, many forms but can be broken down into two general areas:

Calculations & Modeling, which depend on the problem and questions to be answered

Academic Math Skills that are required in STEM majors vary depending on the subject major:

Arithmetic⇆*Algebra*⇆*Calculus*⇆*Differential Equations*⇆*Partial Differential Equations*⇆*Linear Algebra*⇆*Non-linear Equations*⇆*Non -deterministic Systems*

CHEM 106 only requires the ability to accurately add, subtract, multiply, divide, and compare values.

Chemistry ⇆ Physics ⇆ Engineering
The Scientific Method (A Unifying Practice)

- *Energy & Matter: central in all three areas*
  eg. Forces & Gravity
- *Observations: Visible & Measureable*
- *Mathematics: Calculations & Models*

Progressions & Connections:

Arithmetic⇆Algebra⇆Calculus⇆Differential Equations⇆Partial Differential Equations⇆Linear Algebra⇆Non-linear Equations⇆Non-deterministic Systems

RESULTS: Protocols, Explanations, Predictions & Products

Examples: GPS, Cosmology, Space Travel, Space Probes, New Materials: Structural, Mechanical, Industrial & Molecular

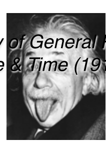
https://www.youtube.com/watch ?v=IY3XV_GGV0MSpace [5min]

https://www.youtube.com/watch ?v=7CuYx9mZCQA

https://www.youtube.com/watch ?v=OiTiKOy59o4

Law or Theory of Gravity?

Hipparchus and Erastothenes (~ 270 B.C.
Galileo (~1600) & Isaac Newton (1687)



Theory of General Relativity:
Space & Time (1915-2015)

The key idea of Einstein's theory of general relativity is that gravity is not an ordinary force, but rather a property of space-time geometry.

https://www.youtube.com/watch ?v=wtsNOMTlS7E

Which falls faster, a feather or a hammer?
……. in a vacuum? …… on the moon?

Do objects made of different materials with different masses accelerate at the same speed when dropped? (Equivalence Principle)

Three ways to test the equivalence principle

To tell whether inertial and gravitational mass are the same, scientists can check whether objects made of different materials fall at different rates, orbit at different distances above Earth, or cause a twist in a torsional oscillator. The twist would come about if the net force produced by gravity's pull toward the center of Earth and the centrifugal force produced by Earth's rotation pointed in a different direction for each weight.

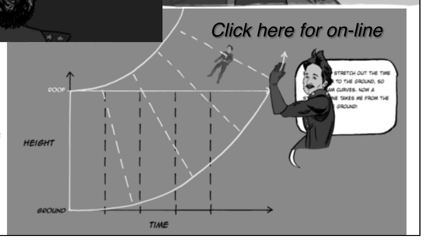
Adrian Cho Science 2015;347:1096-1099

Science AAAS

Published by AAAS

http://spark.sciencemag.org
/generalrelativity/?int-cmp=print-comic

Click here for on-line



The comic book
Adrian Cho, Science, 6 March 2015: 1094-1095.
A superquick, superpainless guide to the theory that conquered the universe.

Click here for pdf

Theory of General Relativity:
Space & Time (1915-2015)

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http://www.einstein-online.info/spotlights/gr
http://einsteinpapers.press.princeton.edu
/vol6-doc/262

25. "The Field Equations of Gravitation"

https://www.youtube.com/watch
?v=foRPKAKZWx8

$$ds^2 = -c^2dt^2 + R(t)^2\left(\frac{dr^2}{1-kr^2} + r^2d\theta^2 + r^2\sin^2\theta\, d\phi^2\right)$$

Theory of General Relativity:
Space & Time (1915-2015)

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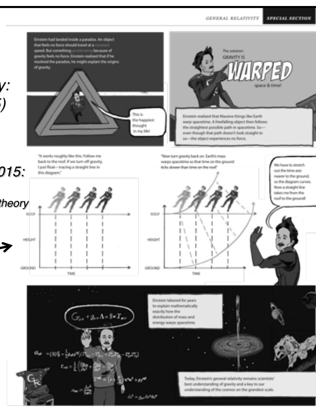
Adrian Cho, Science, 6 March 2015: 1094-1095.
A superquick, superpainless guide to the theory that conquered the universe.

LOOK HERE →

(It is a clear visual explanation of Einstein's theory.)



But is there a LAW of Gravity?

New York Times, July 12, 2010

http://www.nytimes.com/2010/07/13/science/13gravity.html?_r=1&ref=space

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The LAW or THEORY of Gravity?

High Energy Physics – Theory

On the Origin of Gravity and the Laws of Newton

Erik P. Verlinde

(Submitted on 6 Jan 2010)

Starting from first principles and general assumptions Newton's law of gravitation is shown to arise naturally and unavoidably in a theory in which space is emergent through a holographic scenario. Gravity is explained as an entropic force caused by changes in the information associated with the positions of material bodies. A relativistic generalization of the presented arguments directly leads to the Einstein equations. When space is emergent even Newton's law of inertia needs to be explained. The equivalence principle leads us to conclude that it is actually this law of inertia whose origin is entropic.

Comments: 29 pages, 6 figures
Subjects: High Energy Physics – Theory (hep-th)
Cite as: arXiv:1001.0785v1 [hep-th]

http://arxiv.org/abs/1001.0785

Chemistry ⇆ Physics

Law vs. Theory

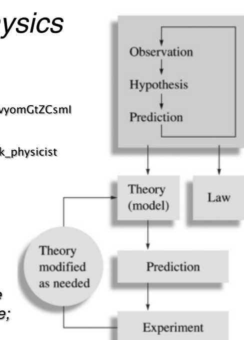
A New Explanation of Gravity
http://www.youtube.com/watch?v=vyomGtZCsml

The Case of Gravity
http://www.science20.com/hammock_physicist
/it_bit_case_gravity

Law(s)? vs. Theory

Spinoza Prize €2.5 x 10^6

"The NWO Spinoza Prize is the highest Dutch award in science; that is awarded to Dutch researchers who rank among the absolute top of science."



QUESTION

The difference between a scientific law and a scientific theory can, at times, be confusing. For example, we will refer to the "Atomic theory" or perhaps the "Law of Gravity." Should the Law of Gravity be changed to the Theory of Gravity?

A. Yes, no one can see gravity, it is better described as a theory.
B. No, scientific laws are based on summaries of many observations and gravity observations are well known and predictable. More than one theory may explain the observations.
C. Yes, gravity is better described as a theory because gravity explains why masses attract each other and theories are about explaining observations.
D. No, keep it as a law, laws offer explanations and gravity explains why masses attract each other and laws are about explaining observations.

Answer

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D. No, keep it as a law, laws offer explanations and gravity explains why masses attract each other and laws are about explaining observations.

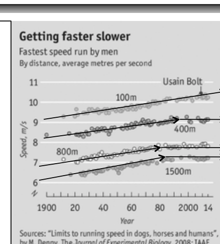
Some Possible Steps in the Scientific Method

1. *Observations*
   - *qualitative (general, descriptive, subjective)*
   - *quantitative (numbers, values)*
2. *Formulating hypotheses*
   - *possible explanation(s) for the observation(s)*
3. *Performing experiments*
   - *gathering new information*
   - *testing whether the hypotheses are valid*
4. *Developing a theory*
5. *Testing & Refining*

Applying the Scientific Method

Why have sprinters not reached a plateau?

1. *Observations: See Data*
2. *Formulate a hypothesis:*
   a possible explanation or explanations for the observations
3. *Outline a possible experiment*
   - *to gather new information*
   - *to test whether your hypothesis is valid*



"Citius, altius, fortius, numerus" Economist, July 18th 2015

Chemistry (CHEM 106)

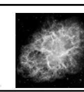
The Study of Energy & Matter

- *In all forms & all behaviors*
- *Sub-categories (not so distinct any longer)*

*Can **all** matter and energy be observed directly?*

Organic: carbon
Inorganic: non-carbon
Organometallic: organic + inorganic
Analytical: what?, how much?, how pure?
Chemical Biology: living organisms
Physical: energy, changes, rates
Nuclear: chemistry of the nucleus
Environmental: interdisciplinary, eg. Ecology, Oceanography

Energy & Matter



$E = mc^2$

http://energy.gov/articles/livestream-our-latest-nobel-prize-winner

Based on the standard model of cosmology, the total mass/energy of the universe is comprised of 4.9% ordinary matter, 26.8% dark matter and 68.3% dark energy.[1][2] Thus, dark matter is estimated to constitute 84.5% of the total matter in the universe and 26.8% of the total content of the universe.[3]

Dark matter is matter that is undetectable by emitted or absorbed radiation, but whose presence can be inferred from gravitational effects.

1) Ade, P. A. R.; Aghanim, N.; Armitage-Caplan, C.; et al. (Planck Collaboration) (22 March 2013). "Planck 2013 results. I. Overview of products and scientific results – Table 9.". Astronomy and Astrophysics (submitted). arXiv:1303.5062. Bibcode:2013arXiv1303.5062P.
2) Francis, Matthew (22 March 2013). "First Planck results: the Universe is still weird and interesting". Arstechnica.
3) "Planck captures portrait of the young Universe, revealing earliest light". University of Cambridge. 21 March 2013. Retrieved 21 March 2013.

Percent

A comparison based on normalization to 100.

- *George Washington University:*
- *64 unsealed addressed envelopes with $10 in each were dropped on campus in two different classrooms.*
- *In economics 18 of 32 were mailed back, in [business, history and psychology] 10 of 32 were mailed. What is the percent for each of the 2 groups of students?*

Percent

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- *64 unsealed addressed envelopes with $10 in each were dropped on campus in two different classrooms.*
- *In economics 18 of 32 were mailed back, in [business, history and psychology] 10 of 32 were mailed. What is the percent for each of the 2 groups of students?*

18 envelopes / 32 envelopes (total) x 100 = 56%
10 envelopes / 32 envelopes (total) x 100 = 31%

Percent Continued

- *The Professor conducting the study received 43.75% of the original $640 in the mail. How much did he receive?*
- *Would you mail the envelop presuming no one knows you found it?*
- *One student mailed an empty envelop with the return address:*
- *Mr. IOU, 1013 Indebted Lane, Bankrupt City, MS*

Did the professor count this envelope in the data?

(WSJ 1/18/95)

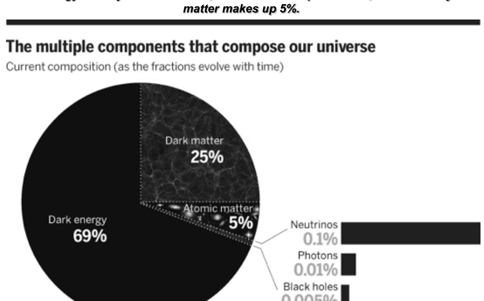
Percent Continued

- *The Professor conducting the study received 43.75% of the original $640 in the mail. How much did he receive?*

  $640 x 43.75% / 100% = $280
- *One student mailed an empty envelop with the return address:*
- *Mr. IOU, 1013 Indebted Lane, Bankrupt City, MS*
- *Did the professor count this envelope in the data?*

NO, "28 mailed back" / 64 total x 100 = 43.75%

Fig. 1 The multiple components that compose our universe.Dark energy comprises 69% of the mass energy density of the universe, dark matter comprises 25%, and "ordinary" atomic matter makes up 5%.

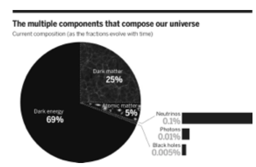


David N. Spergel Science 2015;347:1100-1102

Published by AAAS

Science AAAS

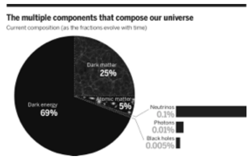
QUESTION



The estimated total mass of observable ordinary atomic matter in the universe is 10^{53} kg. Based on this estimate, the amount of dark matter is:

A. 25×10^{53} kg
B. 10^{265} kg
C. 5×10^{53} kg
D. 1×10^{53} kg
E. 30×10^{53} kg

Answer



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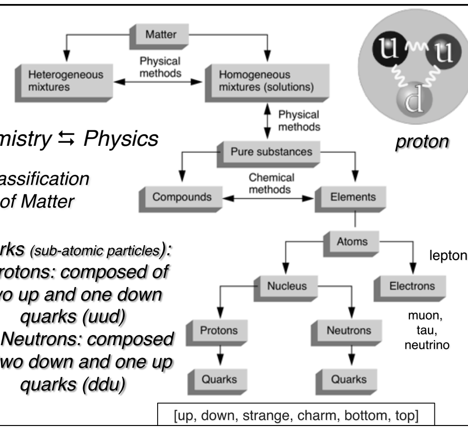
D. 1×10^{53} kg
E. 30×10^{53} kg

$= (25\% \times 10^{53}) / 5\%$

Chemistry ⇆ Physics

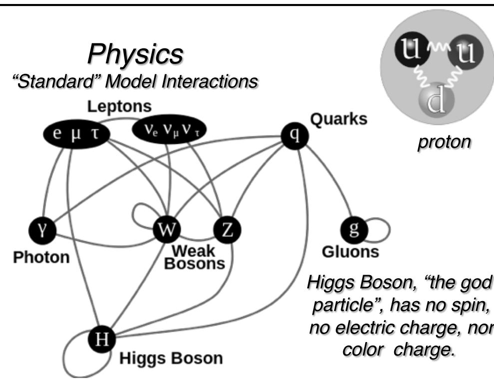
Classification of Matter

Quarks (sub-atomic particles):
** Protons: composed of two up and one down quarks (uud)*
** Neutrons: composed of two down and one up quarks (ddu)*



Physics

"Standard" Model Interactions

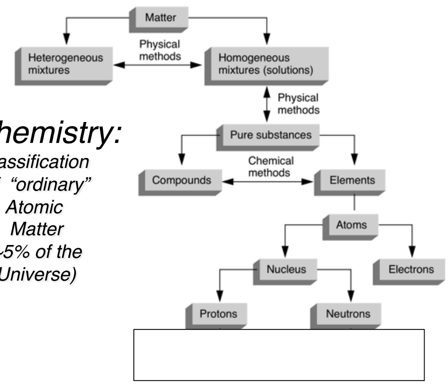


Higgs Boson, "the god particle", has no spin, no electric charge, nor color charge.

Classical vs Quantum Theory.

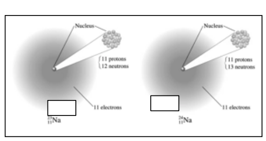
Chemistry:

Classification of "ordinary" Atomic Matter (~5% of the Universe)



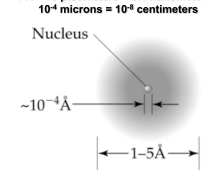
Atoms (CHEM 106)

- *Atoms consist of 3 sub-atomic particles*
  - *# Protons = Atomic Number = Unique Name*
  - *# of Neutrons [different numbers = isotopes]*
  - *# of Electrons [different numbers = ions]*

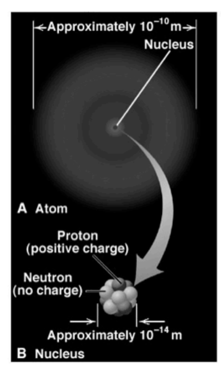


General Features of the Atom

Anders Jöns Ångström
(1814-1874)
1 Å = 10 picometers = 0.1 nanometers = 10^{-4} microns = 10^{-8} centimeters



- *1 nm = 10 Å*
- *An atom vs. a nucleus ~10,000 x larger*



~ 0.1 nm

Nucleus = 1/10,000 of the atom

CHEMISTRY of the Atom

FUNDAMENTAL PARTICLES:

	Mass	Charge	Symbol
Nucleus:			
• PROTON	1 amu	+1	H+, H, p
• 1.67×10^{-27} kg			
• NEUTRON	1 amu	0	n
• 1.67×10^{-27} kg			
• ELECTRON	very small	-1	e^-
• ≈ 2000 x smaller than a proton or neutron			

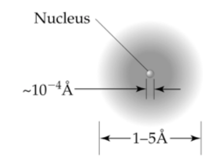
The particle is said to "hold" or "bond" atoms together in molecules.

---

http://science.kqed.org/quest/video/the-worlds-most-powerful-microscope/

Can we "see" and manipulate individual atoms using a microscope?

With TECHNOLOGY: Yes, using atomic force microscopy (AFM) and a variety of instruments such as Scanning Transmission Electron Microscopes.

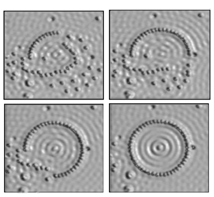


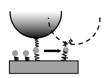
• *1 nm = 10 Å*
• *An atom vs. a nucleus ~10,000 x larger*

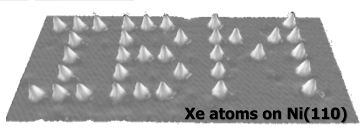
TEAM 0.5:
LBL's
***T**ransmission*
***E**lectron*
***A**berration-corrected*
***M**icroscope*
Resolution:
+/- 0.5 Å

Atomic/molecular structures atom-by-atom

Building a quantum "corral" with Fe atoms on Cu

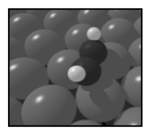


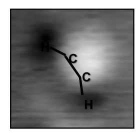




STM images courtesy of Don Eigler, IBM, San Jose

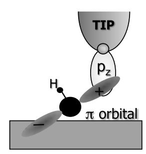
Imaging: acetylene on Pd(111) at 28 K

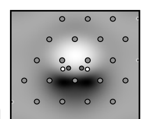




Molecular Image
Tip cruising altitude ~700 pm
Δz = 20 pm

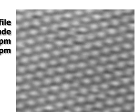
Why don't we see the Pd atoms?
Because the tip needs to be very close to image the Pd atoms and would knock the molecule away



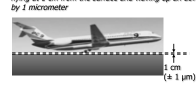


Calculated image (Philippe Sautet)

Surface atomic profile
Tip cruising altitude ~500 pm
Δz = 2 pm



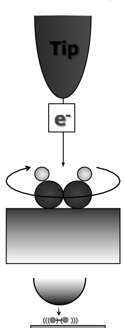
If the tip was made as big as an airplane, it would be flying at 1 cm from the surface and waving up an down by 1 micrometer

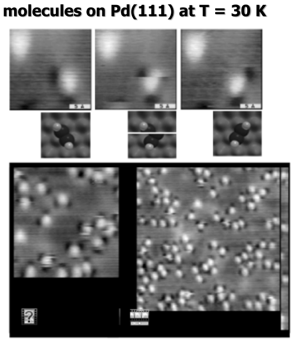


The STM image is a map of the pi-orbital of distorted acetylene

M. Salmeron (LBL)

Excitation of frustrated rotational modes in acetylene molecules on Pd(111) at T = 30 K





M. Salmeron (LBL)

Diameter 8.8×10^26 m
Volume 4×10^80 m^3
Mass (ordinary matter) 10^53 kg
Density 9.9×10^−30 g/cm^3
(equivalent to 6 protons per cubic meter of space)
Age 13.799±0.021 billion years
Average temperature 2.72548 K