NOTE: The hurricane Harvey and Hurricane Irma slides shown here are for your interest as we discussed these in class in the early part of the semester. As we will be covering hurricanes later in the semester, hurricane information will not be included in Exam 1.

Welcome to Planet Earth –
EAPS 10000 001, 3 credits, Tu/Th
12:00 noon – 1:15 p.m., EE 129

EAPS 100 – Planet Earth

Textbook: Foundations of Earth Science
Lutgens and Tarbuck

Course Topics:
Introduction (fundamentals, skills, review)
Earth Science (Geology)
Oceanography
Atmospheric Science (Meteorology)
Astronomy (Earth’s place in solar system and universe)

Format: Lecture (PowerPoint, Slides, Videotapes, Quizzes and In-class activities)
Reading in Textbook
3 one-hour exams
Homework
Handouts: Course outline/syllabus

Blackboard is only used for the grade book. All other course information is available at:
http://web.ics.purdue.edu/~braile/eas100/eas100home.htm

EAPS 100 – Planet Earth, Requirements:
1) Lectures and Reading in Text (Attendance)
2) Exams (One hour, covering previous ~5 weeks of material, skills, review)
   Midterm (6th week) ~20%
   Midterm (11th week) ~20%
   Final (Final Exam week) ~20%
3) Quizzes and In-class activities ~10-15%
   (8-10 unannounced)
4) Homework (6-7) ~25-30%

Total points for semester ~525

How do points predict final grade?

Pre-Test score is not a good predictor.

Pre-Test score vs. Total Points

One Student’s scores

Pre-Test score

r = correlation coefficient

(1.0 = perfect correlation)

r = 0.43

There is also an online EAPS 100 course, so in any email message, please identify yourself as being in the "lecture", "T/Th" or "001" EAPS 100 course.
How do points predict final grade?

As expected, Exam score is a better predictor, but $r$ is still fairly low.

It's more than just the 30 points lost by missing 3 quizzes (and it might be only 10 points lost as we drop 2 lowest scores). It also reflects a lower performance and learning.

The next 6 slides present evidence, based on research, on the importance of note-taking in class! Please review!

Although, there is considerable scatter, it is clear that Average Exam Score correlates with Incoming GPA.

“Scatter plot of students’ incoming GPA versus average exam score, illustrating that students with higher incoming GPAs tended to get higher exam scores than those with lower incoming GPAs”
Looking more carefully at additional data on the students in the previous slide (Average Exam Scores vs. Incoming GPA), the table below shows that Attendance (alone) and Answering Questions (such as with “clickers”) are not strong indicators of successful learning strategies (comparing students with GPA > 3.5 with students with GPA < 3.0).

<table>
<thead>
<tr>
<th>Student Behavior</th>
<th>Incoming GPA</th>
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<tbody>
<tr>
<td></td>
<td>&gt;3.5</td>
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<tr>
<td>Attendance</td>
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<tr>
<td>Answered Questions</td>
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<tr>
<td>Answered Questions Correctly</td>
<td>100%</td>
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<td>Noted Confusion</td>
<td>100%</td>
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<tr>
<td>Volume of Notes</td>
<td>100%</td>
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Continued on next slide...

Looking more carefully at additional data on the students in the previous slide (Average Exam Scores vs. Incoming GPA), the table below shows that students with GPA > 3.5 were about 3 times as likely to have Noted Confusion in their in-class notes, and 4 times as likely to have a substantial Volume of Notes as compared to students with GPA < 3.0!

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From Perry Samson (except in red, above), U. of Mich. (From Table 1. in: https://er.educause.edu/articles/2015/8/promoting-engagement-in-larger-classes)

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L. Braile Home Page:
http://web.ics.purdue.edu/~braile
EAS 100 Home Page:
http://web.ics.purdue.edu/~braile/eas100/eas100home.htm
Or, just do a search for braile

Also, “taking notes” (!): does not have to be a large volume of notes; the more important aspects are: consistently taking notes each class period (add a date to each day’s notes), and focusing on the most important concepts and terms in that class period.

---

EAPS 100 Home Page: to find – search on braile
EAPS 100

Almost all the PPTs shown in class (in pdf format) will be available for viewing and study from this link.
These pdfs will be updated about one week before each exam.

---

EAPS 100 Home Page: to find – search on braile
EAPS 100

Almost all the PPTs shown in class (in pdf format) will be available for viewing and study from this link.
These pdfs will be updated about one week before each exam.
Why (Geo-) Science???
1. Excellent subject for learning fundamental scientific principles
2. We interact with geoscience every day
3. Importance to future – Energy, climate, environment, natural hazards
4. Scientific literacy – increasingly technological society
5. Increasing awareness and enjoyment of the Earth
6. Science education (for teachers)

Earth Sciences: Although somewhat “unknown” to the public, and not one of the “big” sciences, the Earth Sciences are critically important to our world and to our future! Challenges that we face today, and for a sustainable future of the U.S. and the world, rely on understanding and applications in Earth Sciences.

Importance of Earth Sciences to our future
1. Energy (fossil fuels, geothermal, wind, solar, nuclear)
2. Natural Resources (minerals, water, soils, National Parks/recreation)
3. Natural Hazards (earthquakes, tsunami, volcanic eruptions, landslides, hurricanes, tornadoes, floods, asteroid and comet impacts)
4. Environment/Sustainability (climate change, pollution, toxic waste, air and water quality)

Earth, ocean and atmosphere processes are dynamic. We interact with the Earth, the oceans and the atmosphere every day!
These processes have shaped and changed the solid Earth, oceans and atmosphere over time.
Occasionally, these processes cause sudden, sometimes violent events that we refer to as natural hazards.
Some examples:
Aug. 16, 2012 (Thursday) “Shelf” or “Roll” cloud (Lafayette Journal and Courier, Aug. 17, 2012)

California Drought Effects, 2011-2014 (USA Today, 9/3/2014; Oroville is in Northern California)

Shasta Reservoir, 2015
Western U.S. Drought and Wildfires, USA Today, August 9, 2015

Wildfires, USA Today, August 9, 2015

What percentage of U.S. wildfires are human-caused?

About 90%.

Sources: National Weather Service, AccuWeather, National Park Service, Doyle Rice and Karl Gelles @USATODAYWeather

Wildfires, USA Today, August 25, 2015 (News reports state that it is about 95% in California)

Aug. 23, 2011 M5.3 Colorado and M5.9 Central Virginia Earthquakes

Aug. 24, 2014 M6.0 Napa, California Earthquake (Journal and Courier, 8/25/2014)

Feb. 27, 2010 M8.8 Chile Earthquake – Historical Seismicity
Feb. 27, 2010 M8.8 Chile Earthquake – Cross-Section View

Feb. 27, 2010 M8.8 Chile Earthquake – Seismic Gap

Feb. 27, 2010 M8.8 Chile Earthquake – Damage to Alto Rio Building, Concepcion, Chile

EAPS 100 – Planet Earth
Professor L. Braile
2271 HAMP (CIVL), braile@purdue.edu

Welcome to Planet Earth –
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Feb. 27, 2010 M8.8 Chile Earthquake – Damage to Alto Rio Building, Concepcion, Chile

At least 20 tornadoes (one EF 3 tornado in Kokomo) in Indiana August 24, 2016 (Lafayette Journal and Courier, Aug. 25, 2016)

A magnitude 6.2 earthquake occurred in a mountainous region in Italy at a depth of 6–10 km. Early reports indicate that 120 people have been killed and many more are trapped under debris.

The earthquake woke residents in Rome, nearly 160 km (100 miles) to the southwest. In the hours following this earthquake, the area continues to experience aftershocks.

The sun rises over collapsed buildings following an earthquake in Amatrice, central Italy, Wednesday, Aug. 24, 2016. A strong earthquake in central Italy reduced three towns to rubble as people slept early Wednesday, with early reports that many were killed and many more injured as rescue crews raced to dig out survivors.

(Massimo Percossi/ANSA via AP)
Towns across three regions, Umbria, Lazio and Marche, were devastated by the earthquake, which could be felt as far away as Bologna in the north and Naples in the south.

At least 290 people killed

M6.2 earthquake in Italy, August 24, 2016 (CNN.com)
Aerial view of the church of Santa Maria della Misericordia in Accumoli in central Italy, Aug. 26, 2016, where a strong quake hit early Wednesday. (Photo: Localteam/AP)
Tropical cyclone genesis locations (1851-2009) for August 21-31 (http://www.nhc.noaa.gov/climo/#hrhm)

All North Atlantic and Eastern North Pacific hurricanes (at least Category 1 on the Saffir-Simpson Hurricane Scale; http://www.nhc.noaa.gov/climo/#hrhm)

“Earth-like” planet (Proxima b) discovered orbiting Proxima Centauri, the star nearest to our Sun and “only” 4.2 light years away from us (USA Today, August 25, 2016)

This artist’s impression shows a view of the surface of the planet Proxima b.

“Earth-like” planet (Proxima b) discovered orbiting Proxima Centauri, the star nearest to our Sun and “only” 4.2 light years away from us (USA Today, August 25, 2016)

Japan Earthquake, March 11 2011, M9.0


Up to 10 m high tsunami waves hit coastal area near Sendai, in northern Honshu, Japan

Tsunami (still propagating through Pacific Ocean ~6 days later)

Max. Amplitude ±2.0 meters
Tsunami Damage Near Sendai

Tsunami Damage from the Tohoku [Northern Honshu, Japan] M9.0 Earthquake of March 11 – Satellite View before Tsunami

Tsunami Damage from the Tohoku [Northern Honshu, Japan] M9.0 Earthquake of March 11 – Satellite View after Tsunami

Winter storm, January 9-10, 2009

Winter storm, Jan. 11-12, 2011 (2 ½ -hr loop, 10:00-12:30 GMT Jan. 12, 2011; from intellicast.com)

Surface temperature image, January 2011 - Surface air temperature is -15F. Optical phenomena produced by light reflected from hexagonal crystals or plates, as well as hexagonal plate crystals, consisting of an arc produced by reflection of light from "horizontal mirrors" or plates, and by sun dogs. (See above for more details.) Color spectrum of light is distinctly present in both sun dogs. Photo taken inside shows a window reflection, which is not a part of the solar optical phenomena.

Contributed by E. Agee, Department of Earth, Atmospheric, and Planetary Sciences, Purdue University.

Median Earnings vs. Level of Education

Not everyone is motivated by money (USA Today, April 28, 2011; survey of high school seniors)
Another reason:
Health – an 8-9 year increase in life expectancy (USA Today, May 15, 2012)

In-class Activity
“Draw a Scientist”

1. Draw a sketch of a scientist

2. Examine the drawings of a few people near you. What are the common attributes of the scientists in these drawings?

3. Write on your paper:
   - your name (Please always write your name clearly on papers.)
   - 4 attributes or characteristics of the scientists

4. Hand in at end of class (10 points)

- What characteristics did you observe in your sketches?
- Lead-in to discussion about what is science and the scientific method
- Used to illustrate common stereotype and attempt to adjust their view of science
   (This is actually a classic activity that has been used with students of all ages, and adults)
   Be sure to hand in your scientist drawing paper (first quiz) with your name clearly written on it – front of room or, on one of two desks by aisles in back of room.

Scientist Drawings – 5th grade students

Lab coat
Chemistry Experiment
Lab Coat
Pens
Results

- Scientist drawings:
  - Glasses: 94%; Labcoat: 68%; Pens/Pocket protector: 66%; Bald, weird hair: 56%; Chemistry experiment/test tube, etc.: 36%
  - Male students (college class) drew male scientists 100% of the time; Female students drew male scientists 89% of the time.

Results

- Actual number of female scientists is >30%
- Stereotype (glasses, weird hair or bald, lab coat, male, pens in pocket or pocket protector, chemistry experiment – “the mad scientist” stereotype)
- This stereotype is firmly ingrained in students as young as 2nd grade and does not change!

How is this stereotype formed?
Women with STEM undergraduate degrees in Math, science, engineering and computer science over the past 40 years (USAToday, Oct. 15, 2012)

"Draw a Scientist" Themes
- Chemistry 65%
- Biology/Ecology 15%
- Astronomy 6%
- Computer 6%
- Other 8%
- Earth Science 0%

How is science communicated to the public?

Popular movies: Back to the Future, Independence Day

Discussion of scientist drawings
- Reality versus stereotype
- What does this mean about our views of science?
- Interestingly, these views of science and scientists are ingrained in us at a very early age and usually don’t change


EAPS 100 – Planet Earth
Professor L. Braile
2271 CIVL, braile@purdue.edu

Textbook: Foundations of Earth Science
Lutgens and Tarbuck

If you were not here last time please...
- Pick up the course outline
- blank sheet of paper
So..., what is science?

Science is:

-- Description, organization, search for order, quantification of observations (data and experimental results)
-- Analytical
-- Quantitative
-- Constantly changing and being refined
-- Conclusions based on observations
-- Rational

"The Scientific Method" (2 Views)

1. -- Observation and Measurement
   -- Analysis
   -- Inference
   -- Conclusions
2. -- Hypothesis (prediction)
   -- Experiment (hypothesis testing) [Observation]
   -- Theory
   -- Law

"Science is a method for testing claims about the natural world, not an immutable compendium of absolute truths."

-- Stephen Jay Gould

Bully for Brontosaurus, 1991, p. 437
Science is **NOT**:

-- Constant
-- Truth
-- Based only on belief
-- Magic tricks and “flashy” demos

**Examples of pseudo-science:**

-- Astrology
-- Almost anything printed in “Enquirer,” “Weekly World News,” “Globe,” “Star,” etc. (grocery store tabloids)

**Pre-Test – Not for a grade.**

1. **Metric system review:**
   a. 30 cm is about how many inches?
      (1) 6 in.  (3) 36 in.
      (2) 12 in. (4) 92 in.
   b. The temperature in Miami yesterday was about 82° Fahrenheit. What is this temperature on the **Celsius** scale?
      (1) 15°C  (3) 28°C
      (2) 22°C  (4) 35°C
   c. The distance from Lafayette to Indianapolis is about 60 miles. This distance is how many kilometers?
      (1) 40 km  (3) 150 km
      (2) 100 km (4) 180 km
   d. A person who weighs 165 pounds would weigh how much in **kilograms**?
      (1) 20 kg  (3) 75 kg
      (2) 40 kg  (4) 105 kg
   e. What is a **microgram**?
      (1) 0.1 g  (3) 10^4 g
      (2) 0.001 g (4) 10^6 g

2. **Applied math and graph interpretation review:**
   a. The number 5x10^5 is equal to:
      (1) five thousand (5000)
      (2) five hundred thousand (500,000)
      (3) five million (5,000,000)
      (4) five billion (5,000,000,000)
d. A person who weighs 165 pounds would weigh how much in kilograms?
   (1) 20 kg (3) 75 kg
   (2) 40 kg (4) 105 kg

e. What is a microgram?
   (1) 0.1 g (3) $10^{-6}$ g
   (2) 0.001 g (4) $10^{-9}$ g

2. Applied math and graph interpretation review:
   a. The number $5 \times 10^6$ is equal to:
      (1) five thousand (5000)
      (2) five hundred thousand (500,000)
      (3) five million (5,000,000)
      (4) five billion (5,000,000,000)
   b. To convert a velocity (speed) expressed in km/s to units of km/hr, one should:
      (1) multiply by 3600
      (2) multiply by 60
      (3) divide by 3600
      (4) divide by 60
   Trick/strategy: Use dimensional analysis (make units work out):
   
   $3600 \text{ s/hr} \times \frac{\text{km/s}}{1} = \text{km/hr}$

   c. A spacecraft is launched from Earth and travels at a constant velocity of 20,000 km/hr directly toward the moon which is 400,000 km from Earth. How long will it take for the spacecraft to get to the moon?
      (1) 10 hours
      (2) 0.05 hours
      (3) 20 hours
      (4) 200 hours

   d. Examine the graph below which shows dimensionless speed (speed divided by the square root of leg length times the acceleration of gravity) plotted versus relative stride length (length of step) for various animals walking or running. What is the approximate slope of the line shown on the graph?
      (1) 0.50
      (2) 0.75
      (3) 1.3
      (4) 2.00
      (5) 6.00

   e. We observe dinosaur footprints in a sandstone which indicate a stride length of 4 meters. Using the relationship on the graph, what is the estimated dimensionless speed of this dinosaur?
      (1) 1.0
      (2) 2.4
      (3) 4.0
      (4) 0.5
      (5) 6.0

FIGURE 3.13. A graph of relative stride length against dimensionless speed for various animals, including humans. Data from Alexander 1975 and Alexander 1993.
Dimensionless speed versus Stride length for walking and running animals

2e. Dimensionless speed ~ 2.4 (answer 2)

2d. slope ~ 1.3 (answer 3)

Don't count squares!
(twoaren't always the same size)

To calculate slope, don't just “count squares” – that ONLY works when the squares are one unit by one unit on each side.


Stride (m)

Leg length (m)
3. We observe that the moon revolves around the earth approximately every 28 days. We also observe that we always see the same side of the moon from Earth. What does this imply about the rotation (about its axis) rate of the moon and the direction of its axis of rotation? (A sketch might help you answer this question).

4. What is the cause of seasons on Earth?

The complete Pre-Test can be found on the EAPS 100 Web page (Select Handouts from Home Page)

---

**Metric! Metric! Metric!**

Why Metric?
A. The metric system is much easier. All metric units are related by factors of 10.
B. Nearly the entire world (95%), except the United States, now uses the metric system. U.S. economic competitiveness would be strengthened by converting to the metric system.
C. Metric is used exclusively in science — therefore, understanding of scientific and technical issues by non-scientists will be enhanced if the metric system is universally adopted.
D. Because the metric system uses units related by factors of ten and the types of units (distance, area, volume, mass) are simply-related, performing calculations with the metric system is much easier thus facilitating quantitative analysis and understanding in science. That is, mathematical manipulations using the metric system are easier which leads to fewer mistakes and less confusion and increases the chance that scientific principles and concepts can be understood!

---

**EAPS 10000 – Planet Earth**
Professor L. Braile
2271 HAMP (CIVL), braile@purdue.edu
(Also note Study Guide to the text book)

If you were not here last time, please…
- Pick up the course outline/syllabus
- blank sheet of paper, and draw a sketch of a scientist – hand in at the end of the hour (or next time) – this is Quiz 1 (10 points)
Hurricane Lane (now a Tropical Storm) 16:30 – 20:30 GMT, Aug. 25, 2018. Hilo Airport reported 31.85 inches of rain in three days (15 inches on 8/24) – the wettest 3-day period ever observed in Hilo, with records dating back to 1949. Two locations on Hawaii (the big island) reported 45.8 inches in 3 days). Satellite image from intellicast.com.

Infrared satellite image of the tropical, northern hemisphere area of the Pacific Ocean. Note the storm activity in this tropical area (about 0 to 25 degrees North latitude). Also see close-up of Hawaiian Islands area on next slide.


It's exactly one year since Hurricane Harvey that devastated much of Houston and surrounding areas, so it’s appropriate to have a brief discussion of hurricanes. We will go through these quickly as we will return to this topic later in the semester. Hurricane information will not be covered on Exam 1.
Tropical Storm Harvey, Radar, Sunday, August 27, 2017, 6:15 – 8:15 a.m. EDT. (intellicast.com)

Tropical Storm Harvey, Radar, Monday, August 28, 2017, 9:45 – 11:15 a.m. EDT. (intellicast.com)

Tropical Depression Harvey, Radar, Monday, August 29, 2017, 7:45 – 9:15 a.m. EDT. (intellicast.com)

Hurricane Harvey, Infrared Satellite Image, Friday, August 25, 2017, 12:30 p.m. EDT. (intellicast.com)  (Landfall at about 11:00 p.m. Friday)

Hurricane Harvey, Infrared Satellite Image, Saturday, August 26, 2017, 7:00 a.m EDT. (intellicast.com)
Hurricane Harvey, Infrared Satellite Image, Monday, August 28, 2017, 11:15 a.m. EDT. (intellicast.com)

Flooding, impact: so far (likely to change), the loss of life has been small.


Before & After: Flooding on Buffalo Bayou in Houston

And another before and after photo, courtesy of Twitter user Chris Tytherleigh, showing downtown Houston:

Metric! Metric! Metric!

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---

**RESEARCH ON LEARNING CATEGORIES** – How much we retain after one year

1. Attitudes 100%
2. Thinking skills and processes 80%
3. Motor skills 70%
4. Concepts 50%
5. Factual material 35%
6. Nonsense syllables 10%

---

**Scale**

(actual size / model size = scale factor, usually expressed as 1:1 million, for example)

**Importance of Scale**

Significance and understanding of large and small quantities in the geosciences:

Distance scales:
- $10^{-15}$ to $10^{25}$ meters

Time scales:
- $10^8$ to 15 billion years
  - $(1.5 \times 10^{10}$ years)

---

**Countries which have officially adopted the metric system (green). Only three nations have been unable to officially adopt the International System of Units as their primary or sole system of measurement: Burma, Liberia, and the United States.**

---

**Map of countries officially not using the metric system** (Note Metric Handout in HANDOUTS link)


---

**Various Scales**

(actual/model size = scale factor)

Model Car – so, for the model car, an actual car is about 5 m long and the model car is about 15 cm long, so $4.5 \, \text{m} / 15 \, \text{cm} = 450 \, \text{cm} / 15 \, \text{cm} = 30$ (notice that the units cancel)

Dinosaur

State Map

Globe

Solar System
Various Scales  
(actual size/model size = scale factor)

- Model Car: 1:30
- Dinosaur: 1:50
- State Map: 1:1 million
- Globe: 1:40 million
- Solar System: 1:1 billion

Typical roadway of the state of Indiana (such as one you would carry in a vehicle) would have a height of about 0.5 meters. The true N-S distance of the state is almost 500 km, so the map scale is about 1:1 million (500 km/0.5 m).

Globe: Typical diameter is ~30 cm. Earth diameter is ~13,000 km. So scale is 13,000 km or 13,000,000 m divided by 30 cm or 0.30 m. Now the meters cancel, so the scale factor is ~40 million and the scale is written as 1:40 million.

Sun and Earth at 1:1 billion Scale

Checking scale… Distance from the Earth to the Sun
150 m x 1 billion (10^9)
= 150 x 10^9 m
= 150 x 10^6 km
= 150 million km !
(93 million miles)
How much is a billion???

(1 billion = 10^9)

How many is a Billion?
Counting to a billion – or, “a billion seconds”

<table>
<thead>
<tr>
<th>Value</th>
<th>Time Unit</th>
<th>Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>One</td>
<td>10^6</td>
</tr>
<tr>
<td>10</td>
<td>10^1</td>
<td>10 seconds</td>
</tr>
<tr>
<td>100</td>
<td>10^2</td>
<td>1.67 minutes</td>
</tr>
<tr>
<td>1,000</td>
<td>Thousand</td>
<td>10^3</td>
</tr>
<tr>
<td>10,000</td>
<td>10^4</td>
<td>16.67 minutes</td>
</tr>
<tr>
<td>100,000</td>
<td>10^5</td>
<td>2.78 hours</td>
</tr>
<tr>
<td>1,000,000</td>
<td>Million</td>
<td>10^6</td>
</tr>
<tr>
<td>10,000,000</td>
<td>10^7</td>
<td>11.57 days</td>
</tr>
<tr>
<td>100,000,000</td>
<td>10^8</td>
<td>3.17 years</td>
</tr>
<tr>
<td>1,000,000,000</td>
<td>Billion</td>
<td>10^9</td>
</tr>
</tbody>
</table>

1. Revolution (orbit)

Distance = πd (circumference)
= 3.14 x 2 x 150 million km
≈ 9 x 10^8 km
(almost 1 billion km in one year)

Velocity = 9 x 10^8 km / yr × 365 days / yr / 24 hrs / day
≈ 100,000 km/hr
≈ 30 km/s (0.001% of the speed of light)

2. Rotation (about axis; at equator)

Circumference = πd = ~6000 km x 2 x 3.14
≈ 40,000 km

Velocity = 40,000 km / day / 24 hrs / day
≈ 1700 km/hr
≈ 0.5 km/s

Earth rotation and revolution (looking down from above orbital plane, ~ above the North Pole), is counter-clockwise.
If you had Avogadro's number* \((6.022 \times 10^{23})\) of un-popped popcorn kernels, and spread them across the United States of America, the country would be covered in popcorn to a depth of about 15 km (http://www.uky.edu/~garose/avogadro).

*The mole is the unit of measurement in the International System of Units (SI) for amount of substance. It is defined as the amount of a chemical substance that contains as many elementary entities, e.g., atoms, molecules, ions, electrons, or photons, as there are atoms in 12 grams of carbon-12 (12C), the isotope of carbon with relative atomic mass 12 by definition. This number is expressed by the Avogadro constant, which has a value of 6.022140857(74)×10^{23} mol^{-1}. The mole is one of the base units of the SI, and has the unit symbol mol.

http://www.uky.edu/~garose/avogadro

Examples of Scale Illustrations (also some 3-D representations)
Hubble Space Telescope (HST)
Ultra Deep Field Image (2003-04)

- Can image 30\textsuperscript{th} magnitude objects.
- Required 400 orbits, 11.3 days or recording.
- Image contains about 10,000 galaxies.
- Area covers 1/12.7 million of the entire sky.
- Like looking through an 2 ½ m (8 ft) long soda straw. With this view, astronomers would need about 50 Ultra Deep Fields to cover the entire Moon.
- Hubble's keen vision (0.085 arc seconds) is equivalent to standing at the U.S. Capitol and seeing the date on a quarter 400 m (1/4 mile) away at the Washington monument.
Galaxies as far as 13 billion light-years distance

1 Degree of angle (60 arc seconds is 1/60 of this angle!)

60 arc seconds of angle (1/60 of a degree)

Area of night sky covered by the Hubble extreme Deep Field (XDF) view

XDF size compared to the size of the moon – several thousand galaxies, each consisting of billions of stars, are in this small view

Hubble ultra Deep Field (UDF) - close-up

Hubble ultra Deep Field (UDF)

Important concepts for today:
- Radioactive decay; Half-life
- Radiometric Dating
- Uniformitarianism (Uniformity)
- Examples: Glaciations (ice ages); Asteroid, meteor and comet impact

The Geological Time Scale
(see Figure 8.23, text)
Geologic Time Scale: (see Figure 8.23, text) — rock age originally described by name based on locations (i.e. Cambria and Devon in England) of distinctive layers that could be observed or correlated (see Figure 8.15 and 8.17, text) over long distances. After radiometric age dating was developed, absolute ages have been determined for the geologic ages. A simplified geologic time scale (useful for our purposes, and easy to remember) is:

<table>
<thead>
<tr>
<th>Era</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cenozoic (“young life”)</td>
<td>0 to 65 mya*</td>
</tr>
<tr>
<td>Mesozoic (“middle life”)</td>
<td>65 to 251 mya</td>
</tr>
<tr>
<td>Paleozoic (“old life”)</td>
<td>251 to 542 mya</td>
</tr>
<tr>
<td>Precambrian**</td>
<td>542 to 4500 mya</td>
</tr>
</tbody>
</table>

* mya = millions of years ago

** Precambrian is the name used for the vast time period before the Cambrian which is the oldest major time unit of the Paleozoic

Half-Lives of Some Useful Radioactive Isotopes
(also, Table 8.1, text)

<table>
<thead>
<tr>
<th>Radioactive Parent</th>
<th>Stable Daughter Product</th>
<th>Half-Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon – 14</td>
<td>Nitrogen – 14</td>
<td>5730 yrs</td>
</tr>
<tr>
<td>Potassium – 40</td>
<td>Argon – 40</td>
<td>1.3 Billion</td>
</tr>
<tr>
<td>Uranium – 238</td>
<td>Lead – 206</td>
<td>4.5 Billion</td>
</tr>
<tr>
<td>Thorium – 232</td>
<td>Lead – 208</td>
<td>14.1 Billion</td>
</tr>
<tr>
<td>Uranium – 235</td>
<td>Lead – 207</td>
<td>713 million</td>
</tr>
<tr>
<td>Rubidium – 87</td>
<td>Strontium – 87</td>
<td>4.7 Billion</td>
</tr>
</tbody>
</table>

half-life = the time for 50% of the parent material to decay

Geologic Time/Age of the Earth

1. Observations:
   - Oldest rocks on Earth ~ 4.1+ billion years
   - Almost all meteorites ~ 4.5 billion years

2. Age Dating Methods:
   a. Relative age
      - Rates of processes – erosion, deposition,
      -cooling of Earth,
      -accumulation of salt in the oceans

Iron-Nickel Meteorite (Radiometric age dating of meteorites results in consistent age determinations of ~4.5-4.6 billion years)

- Superposition – for layered rocks deposited on the surface, oldest rocks are on the bottom
  - youngest
  - oldest

- Fossils – correlation of rocks with distinctive “index fossils”

- Cross-cutting relationships
  (see figure; also Figures 8.5, 8.6, 8.13, text)
b. Absolute methods
- Rates of processes (when calibrated)
  - Fossils – when age of index fossils (exist over only a short time duration, but are widely distributed) are known
  - Radiometric dating (most important)
    based on spontaneous decay of isotopes (radioactivity) at constant rates (see Figure 8.20, text); examples:

  \[
  \text{Uranium}^{238} \to \text{Lead}^{206} \\
  \text{Potassium}^{40} \to \text{Argon}^{40} \\
  \text{Carbon}^{14} \to \text{Nitrogen}^{14}
  \]

  Rate described by:

  \[
  \text{half-life} = \text{the time for 50\% of the parent material to decay}
  \]
Production and decay of Carbon-14 (Figure 8.21, text)

**Half Lives**

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>100 % Parent (radioactive) Isotopes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>50% remaining</td>
</tr>
<tr>
<td>2</td>
<td>25%</td>
</tr>
<tr>
<td>3</td>
<td>12.5%</td>
</tr>
<tr>
<td>4</td>
<td>6.25%</td>
</tr>
</tbody>
</table>

When the tree dies, falls down and is buried by sediments, it has a fixed amount of $^{14}$C (we'll call it 100% for simplicity) and no longer interacts with its surroundings in the same way. This amount is shown by the partial bar graph above. Now the $^{14}$C in the tree begins to radioactively decay and is not replenished from its surroundings.

After one half life (~5700 years for $^{14}$C), there is 50% of the original $^{14}$C remaining. Because the number of $^{14}$C isotopes has decreased, the number that decay in our sample in the second half life is less even though the rate of decay remains a constant.

After three half lives, there is 12.5% of the original $^{14}$C remaining.

After four half lives, there is only 6.25% of the original $^{14}$C.
We turn this into a bar graph as shown here.

Note that this is an exponential decay, so the % of parent (still radioactive) isotopes decreases rapidly with time, so the curve (blue line) approaches zero after many half lives.

So, after many half lives (say 10 to 15), there is so little parent material remaining that it cannot be measured accurately. For the $^{14}$C method, this is about 70,000 years (due to the short half life of $^{14}$C). For other isotopes (used for rocks, much longer half lives), age dating can extend back millions or billions of years.

To use the $^{14}$C radiometric age dating method, we collect a sample of an organic material, such as part of the dead and buried tree, and measure the amount of $^{14}$C remaining (relative to the amount it had when alive). For example, if there is 12.5% of the $^{14}$C parent material remaining (and 87.5% of the $^{14}$C has decayed into the daughter product $^{14}$N), then the age of the sample is 3 half lives or ~17,100 years old.

The Grand Canyon has one of the best exposures of rocks that extend over ~2 billion years in age.

National Geographic – Amazing Flight Over The Grand Canyon
https://www.youtube.com/watch?v=t6lWJKH1E9Q
John Wesley Powell, the second Director (1881-1894) of the U.S. Geological Survey, is highly regarded in several fields: as an explorer, geologist, geographer, and ethnologist. The Survey’s proud tradition of mapping the nation was largely established under Powell’s leadership.

“In the spring of 1869, the one-armed Civil War veteran led an expedition down the Colorado River into a great, unknown, uncharted territory. Ninety-nine days later, after one of the most daring journeys in American history, John Wesley Powell emerged from the Grand Canyon to become a contemporary American hero.”

https://www.usgs.gov/staff-profiles/john-wesley-powell?qt-staff_profile_science_products=3#qt-staff_profile_science_products

https://www.nps.gov/media/photo/gallery.htm?id=F7BE1F5D-155D-451F-679F22A39AD87BEA

Powell expedition boats in Marble Canyon, Colorado River

https://www.nps.gov/media/photo/gallery.htm?id=F7BE1F5D-155D-451F-679F22A39AD87BEA

http://azgs.arizona.edu/photo/john-wesley-powell-explores-grand-canyon

Grand Canyon, Colorado River rafting route: 188 miles from Lee’s Ferry to Whitmore Wash; some of the notable rapids are listed in italics.

US Highway 89 bridge over the Colorado River at Marble Canyon, Arizona.

Unconformity: a time break in the rock record caused by non-deposition or a period of erosion. Types of unconformities: Disconformity: break in rock record, but sedimentary rocks appear to have had continuous deposition. Angular Unconformity: break in rock record with lower unit having dip/tilt.

Nonconformity: Break in record with igneous or metamorphic rock below.

Also see Figures 8.15 in text.
There are two very prominent unconformities (and several less obvious ones) in the Grand Canyon rock record. The Great Unconformity is along the contact between the Tapeats Sandstone (Ss) and the Vishnu Group consisting of Schist and Gneiss, and, in some areas, the contact between the Tapeats Ss and the Grand Canyon Series. This unconformity represents up to about a Billion years of missing rock units, either not deposited or eroded away before deposition of the Tapeats Ss. The other prominent unconformity is the nonconformity (called an angular Unconformity here) at the contact between the Grand Canyon Series rocks, which were tilted after deposition and partially eroded, and the Vishnu Group. The Great Unconformity nonconformity does not represent a geological boundary. The other hypスタ人物を描いたイラストが描かれている。
Brief geological history of the Grand Canyon area

1. 2000 – 1800 million years ago: Sediments and lavas deposited in the western North American continent as a result of collision with volcanic islands.

2. 1800 – 1200 million years ago: Existing deposits are deformed and metamorphosed at depth (Vishnu schist), intruded (Zoroaster granite) forming a crystalline rock basement, then uplifted and partially eroded.

3. 1200 – 550 million years ago: Deposition of about 3500 m of sediments and lava (now called the Grand Canyon Series, or Grand Canyon Supergroup, or Unkar Group). The boundary between these deposits and the basement rocks below (Vishnu schist and Zoroaster granite) is a prominent angular unconformity.

4. 550 – 525 million years ago: Extension of the Earth’s crust causes faulting and tilting of the Grand Canyon Series rocks. Partial erosion of the tilted rocks removes part of Grand Canyon Series rocks and results in a relatively flat surface that becomes the base of sedimentary rock sequences in the next time period. Deepened and widened the canyon during this time.

5. 525 – 70 million years ago: Deposition (beginning with the Tapeats sandstone) of about 4000 m of mostly marine sedimentary rocks. The base of this sequence (bottom of the Tapeats sandstone) is the contact between older rocks (schist, granite and Unkar sediments) and the younger mostly sedimentary rocks, and is “the Great Unconformity.” Less prominent unconformities occur within this thick section of rocks. Also, the younger rock units of this age range have been eroded and are missing or of limited extent in the Grand Canyon area, but can be correlated with rock units to the North (see Cedar Breaks – Zion – Grand Canyon Region cross section above).

6. 70 – 25 million years ago: Uplift of the Colorado Plateau and adjacent Rocky Mountains area causes significant erosion of the rock units and river drainage which was initially to the North and East. The Colorado River initially carved much of the Grand Canyon during this time.

7. 25 million years ago to the present: Crustal extension causes lowering of the landscape to the west (Basin and Range province) resulting in a change (6-10 million years ago) in the drainage of the Colorado River causing the flow to be similar to what it is today, to the south and west into the Gulf of California. Slow uplift of the Colorado Plateau and the Southern Rocky mountains continued to the present. The river has deepened and widened the canyon during this time.

Unconformities (represent missing times of deposition in the rock record from absence of deposition or erosion of surface rocks)

Angular Unconformity – dipping Unkar group (PreCambrian) sedimentary rocks beneath flat-lying Paleozoic and Mesozoic sedimentary rocks in the Grand Canyon.
Close-up of The Great Unconformity in the Grand Canyon. Tapeats Sandstone above Vishnu Schist metamorphic rocks. The time gap is about 1 billion years!

Close-up of the PreCambrian Zoroaster Granite and intruded fragments of Vishnu Schist (converted to a Gneiss) in Granite Gorge, Grand Canyon.

About 0.5 million years old basalt flows near Lava Falls in the Grand Canyon. The basalt flows into the canyon dammed up the river many times in the past several hundred thousand years. There is evidence from erosion patterns and flood deposits that the damming of the river and subsequent failure of the dams caused very large flood events downstream.

About 0.5 million years old basalt flows (black rocks on the far side of the river) at Lava Falls in the Grand Canyon. The basalt flows into the canyon dammed up the river many times in the past several hundred thousand years. There is evidence from erosion patterns and flood deposits that the damming of the river and subsequent failure of the dams caused very large flood events downstream.

PreCambrian Zoroaster Granite and Vishnu Schist (basement rocks) in Granite Gorge, Grand Canyon.

Details of age dating of basalt flows near Lava Falls in the Grand Canyon. Note Vulcan’s Throne volcano at upper right.
So how old are the rocks, and how old is the canyon in the Grand Canyon area?**

The rocks exposed in the Grand Canyon are 270 to 1750 million years old, although younger rocks are present to the North (see Cedar Breaks – Zion – Grand Canyon slides above) that most likely existed above the youngest rocks in the canyon area. The young (~0.5 million years or less) basalts that flowed into the canyon near Lava Falls clearly show that the canyon existed in close to present form by about 0.5 million years ago (age dating and principle of cross-cutting relationships). Meander loops (similar to above; indications of a low gradient river on relatively flat ground) that are common in the Colorado River north of the Grand Canyon area are rare in the Grand Canyon, and the drainage direction change about 6-10 million years ago (see Geological History slides above) has convinced most geologists that the present canyon in the Grand Canyon area was carved, or at least significantly deepened in the last 10-12 million years.

** Fossils

Some fossils are *index fossils* (widespread, distinctive, limited age range) and provide accurate age information for geologic units.


Orthoceras, Paleozoic-Early Mesozoic fossil
Uniformitarianism (uniformity):

- Analogous to: “Laws of physics are constant”
- “The present is the key to the past”
- By studying modern geologic processes, we can infer past events when we observe the results of those processes displayed in the geologic record - examples: volcanic deposits, sediments in shape of delta, offset of layers by faulting due to an earthquake
- Earth is shaped by slow, continuous processes acting over geologic time

The Grand Canyon has one of the best exposures of rocks that extend over ~2 billion years in age.

Note layers of basalt lava, erupted on the surface, so youngest above and oldest below (superposition). The canyon is younger than the rock units (cross-cutting relationship).
Layered sedimentary rocks, Grand Canyon

[Link](http://www.nature.com/scitable/knowledge/library/dating-rocks-and-fossils-using-geologic-methods-107924044) – this web page has an excellent description of geologic dating methods and results.

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Catastrophism:

- Earth is shaped by sudden, occasional, catastrophic events

  (some events are “once-only” or very rare so are often thought of as catastrophic - -

  examples:

  - differentiation of Earth (crust, mantle, core)
  - development of atmosphere, oceans, life
  - asteroid/comet impacts)

- Modified principle (mostly applied to evolution of species through time) is “Punctuated Equilibrium”

---

Glaciation - - an example of application of the concept of uniformitarianism

(Louis Agassiz, ≈ 1850)

- In modern glaciers and glacial terrane, we observe distinct features (striations, deposits [tills], moraines, drumlins, U-shaped valleys, erratics, etc.)
- Recognition of these features in the geologic record (ancient deposits and landforms, etc.) allows inference of previous glaciations or “ice ages”

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Alpine (mountain) glacier – “A river of ice”

[Figure 4.7, text.](#)
A U-shaped valley results after melting of alpine glaciers (Yosemite valley is a good example).

Figure 4.12, text.

Striations (scratches) and polished rock surfaces indicate glacial ice movement.

Figure 4.15, text.

Striations (Crater Lake, Oregon), also see Figure 4.11, text.

Erratic Glacial till (deposited directly by glacial ice; note mix of sediment sizes)

Also see Figure 4.16, text.

Drumlins (streamlined hills)

Antarctic ice sheet, profile location (A-B) and cross-section, below.

Figure 4.19, text.
Cross-section view (like slicing through a layer cake) through the Antarctic ice sheet – note that the ice sheet is about 3 km thick near the South Pole.

Elevation (meters) 0 – 3000
Sea Level (meters) 0 – 3000

(VERTICAL EXAGGERATION MAKES SLOPES LOOK MUCH GREATER THAN THEY ACTUALLY ARE)

Maximum extent of continental glaciers (ice sheets), Northern hemisphere, last ice age (~20,000 years ago). (Figure 4.24, text)

Comparison of coastlines: past (~18,000 years ago), present, and future (? if ice sheets melt).

Also see Figure 4.18 and 4.22, Lutgens and Tarbuck, 2017.

Meteor Crater, Arizona

NATIONAL GEOGRAPHIC, SEPTEMBER, 2013

Present-day shoreline

NATIONAL GEOGRAPHIC, SEPTEMBER, 2013
Meteor Crater, AZ, 1.2 km, 50 m meteor, 20 MT, http://en.wikipedia.org/wiki/Meteor_Crater

50 m, 20 MT, http://en.wikipedia.org/wiki/Meteor_Crater

Shoemaker-Levy 9 comet after breaking up into about 21 pieces. First discovered on March 24 of 1993, the chain of comets sometimes called “string of pearls,” had been orbiting Jupiter for about 20-30 years. It apparently broke into fragments about July of 1992 and then collided with Jupiter beginning on July 16 to July 22, 1994 with a speed of about 60 km/s (~200,000 km/hr).


The planet Jupiter after Shoemaker-Levy 9 comets collided with the planet. The small dark spot near the top of the image is one of Jupiter’s moons. The larger impact effects are larger than the size of the Earth.


A chain of craters on Ganymede (one of Jupiter’s moons), probably caused by a chain of comets or asteroids similar to (but smaller than) the Shoemaker-Levy 9 impact events. The picture covers an area approximately 190 km across.


Fig. 1. Plane view of the positions of more than 7000 asteroids and the orbits of the planets on October 20, 1991. Small dots are asteroids, circles are orbits of planets. Mercury through Saturn, and solid circles represent the planets. Each asteroid is represented by a dot. The Sun is at the center. Orbital elements are from the Spacewatch Observatory Asteroids (SNOAS) Database (SOARDS).
Heavy Traffic

Every year as the Earth loops through a solar system crowded with other bodies, there's a chance it could run into trouble.

So far more than 54,000 asteroids and comets have been spotted flying within 120 million miles of the sun—close enough for their orbits to possibly cross or collide with Earth. These objects that measure more than 490 feet across and pass within 4.6 million miles of Earth's orbit are considered potentially hazardous. If a light asteroids hits a city, it can create more than 400 such hazardous asteroids—so called because they have the potential to collide with Earth. So astronomers are frequently monitoring these objects, record during their orbit, and the impact sites they intersect—and searching nearby space for new threats.

Orbits of Potentially Hazardous Asteroids (August 14, 2013)
Image Credit: NASA, JPL-Caltech

Photographic time exposure through a telescope. White streaks are stars. The apparent motion is due to the Earth's rotation during the time exposure. The asteroid (~300 m in size), discovered in this image, has a very different apparent motion because it is much, much closer to the Earth.

Orbits of Potentially Hazardous Asteroids (August 14, 2013)
Image Credit: NASA, JPL-Caltech
Asteroid Eros

(33 km long asteroid)

EARTH SCARS
Using tools from satellite imagery to microscopically analyze rocks and minerals, scientists have found traces of 174 meteorite impact sites. Many more have been disturbed by surface changes or lie hidden under the sea. The largest impact cones (red dots) represent events that had the power to transform landscapes, climates, and the Earth across much of the planet.

Kondyor Crater, Siberia
(mining for titanium and other metals)
Manicouagan Crater, eastern Quebec, Canada, ~100 km diameter

Manicouagan Crater, Quebec (NASA)

Chicxulub Crater (Yucatan Peninsula) Gravity Field

Crater is about 200 km in diameter

Bolide Events 1994 – 2013
Small Asteroids that Disintegrated in Earth’s Atmosphere


Approximate initial diameter of meteoroid

Every hour
Every year
Every million years

Crater diameter on Earth

10 m
100 m
1 km
10 km
100 km

(10 m) (100 m) (1 km) (10 km) (100 km)

Every second
Every minute
Every hour
Every day
Every year
Every century
Every millennium
Every million years

Earth's history

Note log-log scales

Frequency of occurrence of natural hazards on Earth (earthquakes, volcano eruptions, hurricanes, tornadoes, flooding, etc.) usually have a frequency vs. size relationship similar to this!

Video of Chelyabinsk meteor impacting the upper atmosphere above Russia, Feb. 15, 2013; energy 400-500 KT (0.4-0.5 MT, about 20 times smaller energy than Meteor Crater event), exploded in the atmosphere at a height of about 30 km; video at 4 times slower speed available at: https://en.wikipedia.org/wiki/Chelyabinsk_meteor

Apollo 17 landing site – Note scale and large numbers of craters

Explanation: This view of the Apollo 17 landing site in the Taurus-Littrow valley was captured last month by the Lunar Reconnaissance Orbiter (LRO), the sharpest ever recorded from space. The high resolution image data was taken during a period when LRO’s orbit was modified to create a close approach of about 22 kilometers as it passed over some of the Apollo landing sites. That altitude corresponds to only about twice the height of a commercial airline flight over planet Earth. Labeled in this image are Apollo 17 lunar lander Challenger’s descent stage (inset), the lunar rover (LRV) at its final parking spot, and the Apollo Lunar Surface Experiments Package (ALSEP) left to monitor the Moon’s environment and interior. Clear, dual lunar rover tracks and the foot trails left by astronauts Eugene Cernan and Harrison Schmitt, the last to walk on the lunar surface, are also easily visible at the Apollo 17 site.

http://apod.nasa.gov/apod/ap110908.html
Cross-cutting craters

Small craters (impacts) after larger crater formed


“A dramatic, fresh impact crater dominates this image taken by the High Resolution Imaging Science Experiment (HiRISE) camera on NASA’s Mars Reconnaissance Orbiter on Nov. 19, 2013. Researchers used HiRISE to examine this site because the orbiter’s Context Camera had revealed a change in appearance here between observations in July 2010 and May 2012, bracketing the formation of the crater between those observations.”

“The crater spans approximately 100 feet (30 meters) in diameter and is surrounded by a large, rayed blast zone. Because the terrain where the crater formed is dusty, the fresh crater appears blue in the enhanced color of the image, due to removal of the reddish dust in that area. Debris tossed outward during the formation of the crater is called ejecta. In examining ejecta’s distribution, scientists can learn more about the impact event. The explosion that excavated this crater threw ejecta as far as 9.3 miles (15 kilometers).”

Conclusion:

Impacts on Earth have been important in Earth history (more frequent in early history) and will occur in the future. They can be catastrophic, but actually represent uniformitarianism. Questions remain such as correlations with extinctions like the dinosaur extinction event 65 million years ago.