Chapter 4
Newton’s laws & gravity

Next topic after this packet: Tides (also in chapter 4)

Goals & Outcomes

• ADD MORE GOALS
• Contrast the conditions on planets with atmospheres with the conditions on airless worlds.
Homework due

• IMPORTANT NOTE:
  – The following homework is due next class:
    • Page 145, questions 22

Science Vocabulary – meanings are different than everyday life

• Velocity – speed AND direction
• Acceleration – any change in velocity
  – Changing speed (getting faster OR slower)
  – OR Changing direction
• Your body feels acceleration, not velocity.
• We’ll focus mostly on accelerations caused by gravity (falling down or falling around)
Calif. Science Standards for motion

- From California Science Standards, grade 2:
  - Students know the way to change how something is moving is by giving it a push or a pull. The size of the change is related to the strength, or the amount of force, of the push or pull.

- And from grade 8:
  - Students know the velocity of an object must be described by specifying both the direction and the speed of the object.
  - Students know changes in velocity may be due to changes in speed, direction, or both.

Science Vocabulary – part 2

- Matter =
  - stuff

- Mass =
  - the amount of stuff

- Force – interaction between 2 bodies:
  - push or pull.
  - Forces make objects accelerate.
  - All accelerations are caused by a force.

- Weight =
  - the force of gravity pulling two objects together*
  - *Your book (P. 123) and I disagree on this. See “weightlessness” slide.

- Which objects are involved in the force of gravity?
  - Ask neighbor: what’s the second object for pencil falling down?
Homework due

• IMPORTANT NOTE:
  – The following homework is due next class:
    • Page 145, questions 29

Gravity near ground

• Free fall
  – Toss something up, what happens on way up?
  – Drop something, what happens on way down?
• When things fall, measure same accel. for:
  – speeding up
  – slowing down.
• Paper/pen experiment; See For Yourself p. 122.
• SAME GRAVITATIONAL ACCELERATION for ALL objects, all masses, everywhere near ground.
• Galileo observed this (in Pisa). Galileo’s observations helped Newton formulate ideas.
From Apollo 15 mission
Men on the Moon

- Show the hammer-feather movie
- Commander David Scott
- August 2, 1971
- Hammer: 1.32 kg
- Feather: 0.03 kg

Homework due

- IMPORTANT NOTE:
  - The following homework is due next class:
    • Page 145, questions 20
PRETEST: Astronauts inside the Space Shuttle float around as it orbits the Earth because (select all that apply)

0  1. there is no gravity in space.
0  2. they are falling in the same way as the Space Shuttle.
0  3. they are above the Earth’s atmosphere.
0  4. there is less gravity inside the Space Shuttle.
0  5. the sky is blue.

Weightlessness

• When have YOU ever felt weightless? [ignore being in water]
• Weightless when you accelerate (fall) as much as everything around you.
  • Weightless scenes in Apollo 13 were filmed this way!

• IMPORTANT NOTE: Your book says weight is the force a scale measures when you stand on it. I don’t care for this definition and won’t use it. Your book discusses weightlessness using its IMHO poor definition of weight. Its discussion is good, but I don’t like the terminology. I prefer the physics version used in these notes.
Falling Around

• Newton’s cannon drawing.
• Gravity’s acceleration can change an object’s direction.
• See Interactive Figure 4.4 for an animation of this.

California Elementary School Science Standards for orbits

• From California Science Standards, grade 5:
  – Students know the path of a planet around the Sun is due to the gravitational attraction between the Sun and the planet.
• And from the high school standard:
  – Students know applying a force to an object perpendicular to the direction of its motion causes the object to change direction but not speed (e.g., Earth’s gravitational force causes a satellite in a circular orbit to change direction but not speed).
  – Students know circular motion requires the application of a constant force directed toward the center of the circle.
Falling around – part 2

• Are orbiting satellites falling? Yes or No?
  – Example: ISS: International Space Station.
• Are the people inside ISS falling? Y/N?
• So, why are they weightless?
• Draw a cartoon in your own notes that illustrates why astronauts are weightless.
• Are they accelerating as they fall? Clicker.

Are the astronauts accelerating while in Earth orbit?

  0  1. Yes
  0  2. No
Are the astronauts speeding up while in Earth orbit?

0 1. Yes
0 2. No

Homework due

• IMPORTANT NOTE:
  – The following homework is due next class:
    • Page 145, questions 21
Newton changed the way people think

- Isaac Newton discovered rules governing velocity, acceleration, force, etc.
- He applied these rules to objects in the heavens (space) and on Earth.
  - First person to do this.
  - He theorized: Scientific ideas are “universal”
- Things change for natural reasons
  - Ex: Motions (velocities) change due to forces

Newton’s 3rd law

- You’ve probably heard this law:
- For every action _______ Force _______
- There is an equal and opposite reaction _______ Force _______.
  - ACTION FORCE:
    If object 1 pushes on object 2, then
  - REACTION FORCE:
    Object 2 pushes equal and opposite on object 1.
  - It does this without “trying.”
What is the REACTION to this action?
SITUATION: You and a friend are on an icy pond.
ACTION: You push on your friend’s back.

0 1. You go (accelerate) backwards
0 2. Friend accelerates forwards
0 3. You both accelerate
0 4. Your friend’s back pushes on you

Newton’s 3rd law examples
How many objects are involved in a force? (non-clicker)
• On skates: you push on your friend’s back.
• Punching the wall (pushing the wall)
• Gravity pulling you down (name for this force is …)
• Walking (or running)
• Rockets blasting off…

<table>
<thead>
<tr>
<th>#</th>
<th>Giver</th>
<th>Receiver</th>
<th>Action force</th>
<th>Reaction force</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Your hands</td>
<td>Friend’s back</td>
<td>Your hands (giver) push on (force) friend’s back (receiver)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
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<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Rocket engine</td>
<td>Exhaust (gas)</td>
<td></td>
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</tbody>
</table>
Error in your Book

• On page 127, at the end of the first paragraph that introduces “Newton’s third law” …
• Book gives an “example of action-reaction”
• This example is VERY misleading and does not match up well with what we discussed
• The examples we did in class are correct.
• The book’s example is misleading.
  – But if you read the book super-carefully, the only official error they make is using the words “offset” and “opposed.” But most people are mislead, because they worded the example VERY POORLY.

• I suggest you skip the example at the end of this first paragraph.

Homework due

• IMPORTANT NOTE:
  – The following homework is due next class:
    • Page 145, questions 33
    • Common Misconception interview of 5 people for the Misconception on page 128, and you should ask: “Can rockets blast off if they’re falling in air? Why or why not?”
California Elementary School
Science Standards for motion

• From California Science Standards, high school
  – Students know that when one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction (Newton's third law).

A semi-truck moving 70mph hits a car moving 50mph in opposite direction. Which force is stronger?

1. Semi-truck getting hit by compact car
2. Compact car getting hit by semi-truck
3. Same
Which force is stronger

0 1. Earth pulling me down
0 2. Me pulling Earth up
0 3. Same

Results of forces

- Newton’s 3rd law says that:
  - all PAIRS of forces are equal. EXAMPLE:
    - Object 1 forcing object 2 = Object 2 forcing object 1.
- It does NOT say
  - Results of the pairs of forces are equal.
- Newton’s 2nd law is about how the equal pairs of forces cause unequal results. \( F = m \times a \)
  - Why the semi “wins” and the car “loses.”
  - Why you see me fall down, not Earth falling up.
- N 2nd law: the low-mass object gets a larger ACCELERATION despite getting the same force. REMINDER: You feel acceleration.
New Topic

• Newton’s Universal Law of Gravity

Universal Law of Gravity:

• Newton hypothesized that gravity’s force depends on three things.
• The mathematical relationship is called an Inverse Square Law and it looks like this:
• FOR ANY 2 OBJECTS (any → Universal)

\[ F_{\text{gravity between 2 objects}} = \frac{G m_{\text{object1}} m_{\text{object2}}}{d^2} \]

G is a number you look up in a book. We'll ignore it. (Usually)
Homework due

- IMPORTANT NOTE:
  - The following homework is due next class:
    - Page 145, questions 23, 30, 32, 36, 37

Gravity is forcing you towards the person next to you.

1. True
2. False
Is there gravity on the Moon?

0 1. Yes
0 2. No

Is there gravity on you if you were in the empty space between the planets?

0 1. Yes
0 2. No

Why not or from what?
Is there such a thing as zero gravity?

1. Yes
2. No

Gravity from multiple objects

For each version of you, draw the direction the yellow planet's gravity pulls you with an arrow. Bigger arrow = stronger force.

Repeat for the grey planet, use a different color or arrow in your notes.
Gravity results from 2 OPPOSING objects

- Grey & yellow planets are **both pulling on** red person in opposite direction: only one of 3 things can happen:
  - Grey Planet forces harder than Yellow Planet
    - Red person *accelerates towards Grey Planet*
  - Yellow Planet pulls harder than Grey Planet
    - Red person *accelerates towards Yellow Planet*
  - The two force equally
    - Red person *doesn’t accelerate*
    - At rest, stays at rest
    - In motion, stays in motion

Which best describes the net force on the person shown, halfway between the 2 twin planets?

- 1. Very strong to the right
- 2. Very strong to the left
- 3. Very strong on each side
- 4. Zero
California Elementary School
Science Standards for motion

• From California Science Standards, grade 8
  – Students know when **an object is subject to two or more forces at once**, the result is the **cumulative effect** of all the forces.
  – Students know **when the forces on an object are balanced**, the motion of the object does not change.
  – Students know that **when the forces on an object are unbalanced**, the object will change its **velocity** (that is, it will speed up, slow down, or change direction).
  – Students know the **greater the mass of an object, the more force is needed to achieve the same rate of change in motion.** (i.e. **acceleration**)

California Elementary School
Science Standards for motion

• From California Science Standards, high school
  – Students know that **forces are balanced, no acceleration occurs**; thus an object **continues to move at a constant speed or stays at rest** (Newton's first law).
Gravity vs. Newton’s 3rd law

- Gravity is a force pulling two objects.
- Newton’s 3rd law (N3L) says forces between two objects act equally on both objects.

Which force is stronger

1. Earth pulling me down
2. Me pulling Earth up
3. Same
Lecture Tutorial

• Work with a partner on the tutorial on pages 29-31
• Fall 2009: Only questions 1-3 in class.
  – 5 minutes.

Now MANY questions about this, after review of this tutorial.
Most of these questions aren’t in your notes, for a reason.

Who is right on question #2?

1. Student #1
2. Student #2
3. Both are right
4. Both are wrong
5. Some of each are right
Forces, Newton’s 3rd law, Gravity

• Student 1 is correct.
• Newton’s 3rd law says both forces must be equal.
• F = Gm₁m₂/d² tells us HOW STRONG the two equal forces are.

Question 3. Does the force between Moon & Earth change if Moon doubles its mass?

1. Yes
2. No
Lecture tutorial question #6

• Where on the picture is the craft getting the strongest net (total) gravitational pull?

Lecture tutorial #6. Which is the best answer from these choices?

1. In the middle
2. Between middle & Earth
3. Between middle & Mars
Best answer to #6

• Wasn’t one of those 3.
• What about where gravity is balanced?
• NET force where balanced = ____

Ranking Task

• NOTE TO TEACHER – go over the following Ranking Tasks
  – Do exercise #1 as a class
  – Calculate the gravity on the top row for exer. 5
• NOTE TO STUDENTS:
  – For exercise #2 & #4: HINT: Newton’s 3rd law.
  – For exercise #7: pretend asteroids are round.
Which of the following would make you weigh half as much as you do right now? Select all that apply.

0 1. Take away half of the Earth's atmosphere.
0 2. Double the distance between the Sun and the Earth.
0 3. Make the Earth spin twice as fast.
0 4. Take away half of the Earth’s mass.

There are two things, not on this list, you could do to weigh half as much. What are they?

IN NOTES: If you were twice as far from Earth as you are now, how would gravity change?

0 1. It would be four times as strong
0 2. It would be twice as strong
0 3. It would be the same
0 4. It would be half as strong
0 5. It would be 1/4th as strong
If the Earth shrank to half its current size but didn’t lose mass, what would gravity be on the new surface?

<table>
<thead>
<tr>
<th></th>
<th>1. It would be four times as strong</th>
<th>2. It would be twice as strong</th>
<th>3. It would be the same</th>
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<tbody>
<tr>
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<td>0</td>
<td>0</td>
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</tbody>
</table>

If the Earth grew to 3 times its current size but didn’t change mass, how would surface gravity change?

<table>
<thead>
<tr>
<th></th>
<th>1. It would be 9 times as strong</th>
<th>2. It would be 6 as strong</th>
<th>3. It would be 3x</th>
<th>4. It would be the same</th>
<th>5. 1/9 as strong</th>
<th>6. 1/6 as strong</th>
<th>7. 1/3 as strong</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
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</table>
Real triple-size planets

• We just said planets that are 3x the Earth’s size have __________ gravity.
• Do you think real planets that are 3x bigger than Earth have weaker gravity?
• Why not?

Which is a stronger force? Read the answers carefully.

1. Earth pulling on you
2. Moon pulling on you
3. Both are the same
Is there a place between the Earth and Moon where the gravity from the Moon is balanced by the gravity from the Earth?

0 1. Yes
0 2. No

Where should that place be?

0 1. Closer to Earth
0 2. Closer to Moon
0 3. Halfway in between
If the Moon got twice as heavy, would your current weight (in this room) change noticeably?

1. Yes
2. No

If the Earth’s atmosphere went away, would your weight change noticeably?

1. Yes
2. No
• Objects falling

You have two balls of equal size and smoothness, and you can ignore air resistance. One is heavy, the other much lighter. You hold one in each hand at the same height above the ground. You release them at the same time. What will happen?

1. The heavier one will hit the ground first.
2. They will hit the ground at the same time.
3. The lighter one will hit the ground first.
Same objects. How does the **acceleration** of gravity compare? Be careful!

0  1. The heavier one has a larger gravitational acceleration.
0  2. They have the same gravitational acceleration.
0  3. The lighter one has a larger gravitational acceleration.

You have two balls of equal size and smoothness, and you can ignore air resistance. One is heavy, the other much lighter. You hold one in each hand at the same height above the ground. You release them at the same time. How does the **force** of gravity compare? Be careful!

0  1. The heavier one has a stronger gravitational force.
0  2. They have the same gravitational force.
0  3. The lighter one has a stronger gravitational force.
California Elementary School
Science Standards for gravity

• From California Science Standards, high school
  
a. Students know the relationship between the universal law of gravitation and the effect of gravity on an object at the surface of Earth.

Gravity causing acceleration

• Planet’s gravity pulls you down.
• If nothing ON YOU resists gravity...
  – you accelerate downwards!
• Remember: force causes acceleration

• Newton’s 2nd Law: \( F_{\text{on you}} = m_{\text{you}}(\text{accel}) \)
• \( F_{g \text{ on you}} = \frac{G M_{\text{Earth}} m_{\text{you}}}{\text{Dist}_{\text{Earth}}^2} \) ...
  Math Trick

  \( F_{g \text{ on you}} = \frac{G M_{\text{Earth}}}{\text{Dist}_{\text{Earth}}^2} m_{\text{you}} \)

  Acceleration is same, but forces are different
  Acceleration of gravity
  Depends only on Earth properties
Masses

• Earth’s mass is $6 \times 10^{24}$ kg. 6 trillion trillion kg.
  – $6,000,000,000,000,000,000,000,000$ kg (24 zeroes)
  – Earth is 60 billion trillion times heavier than a 220 lb person.

• When a pen falls down, why does the pen move & the Earth doesn’t? [clicker question first].
• [continued soon – this slide will reappear shortly]

Which force is stronger?

0 1. Earth pulling down on pen
0 2. Pen pulling up on Earth
0 3. Same
Masses

- Earth’s mass is \(6 \times 10^{24}\) kg. 6 trillion trillion kg.
  - \(6,000,000,000,000,000,000,000,000\) kg (24 zeroes)
  - Earth is 60 billion trillion times heavier than a 220 lb person.

- When a pen falls down, why does the pen move & the Earth doesn’t? [clicker question first].

- Earth DOES accelerate up, VERY slowly!

- Similar to planets tugging on stars. → Found 405* planets around other stars (since 1995**).
  - *as of 11/23/2009
  - **I just saw at exoplanet.eu (NOT edu) 1 was discovered in 1989! The first strong detection was in 1995, though.

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Which is closer to you?

1. New York City
2. The top of Earth’s atmosphere
3. They are the same distance
Gravity’s acceleration in space

- A previous slide showed us: \( F_{\text{grav}} = G \frac{m_1 m_2}{d^2} \)

- What is the numerical distance in the expression above?
- RHETORICAL QUESTION: How does this affect astronauts?
- How far are the astronauts from Earth?
  - Most satellites are 200-300 miles up
  - For a total distance of …
  - Has the distance changed by a big percentage?

- That 5% distance change results in \( \approx 10\% \) weaker gravity
- (How high up does the atmosphere go?)

Astronauts inside the Space Shuttle float around as it orbits the Earth because (select all that apply)

- there is no gravity in space.
- they are falling in the same way as the Space Shuttle.
- they are above the Earth’s atmosphere.
- there is less gravity inside the Space Shuttle.
- the sky is blue.
Escaping – pages 138-139

• Is it true that all things that go up, come back down?
• Does gravity turn off for objects that don’t come back down?
• How can they escape?
  – Newton’s cannon drawing, revisited. P. 139.
• If you go fast enough, Earth’s gravity isn’t strong enough to stop you and pull you back.

• How is that possible?
  – You get further, Gravity gets weaker as you get further.
    – However, gravity will always slow you down
• This speed is called the escape speed

Escape Speed

• The escape speed depends on:
  – the mass of the object you are escaping from, and
  – how far you start from the center of that object.
  – In other words:
    – how strong gravity is when you start moving
• To escape from the surface of the Earth, you have to move 11 km/s (7 miles per sec = 24,000 mph).
• Is it easier or harder to escape Earth if halfway to the Moon? (clicker)
• For the math people out there: the escape speed is
  \[ \sqrt{\frac{2GM_{\text{star or planet}}}{\text{dist}}} = (\sqrt{2})v_{\text{circle}} \]
• To escape from the solar system at the Earth’s position, \( v = 42 \text{ km/s} \) (26 miles/sec)
• Do you need to go faster or slower if near Mercury?
Which best describes the minimum speed to escape from Earth when halfway between Earth & the Moon?

0  1. Faster than 24000 mph (Earth’s \( v_{\text{esc}} \))
0  2. Slower than 24000 mph
0  3. Same speed

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Atmospheric Retention

- Why don’t the atoms and molecules in Earth’s atmosphere escape into space?
- What determines if a world keeps an atmosphere?
  - The gas particles must move slower than the escape speed.
- What determines the escape speed of a world?
- What determines how fast gas particles go?
  - Temperature AND mass of INDIVIDUAL gas particles!
  - Name the 2 least massive elements. Will they move faster or slower than CO\(_2\)?
- Why doesn’t Mercury have an atmosphere? 2 reasons.
- What about the Moon? And if Moon were 10x further?
- Why doesn’t Earth have any gaseous H or He in its atmosphere? Why is it mostly ______________?
- Good discussion on pages 314-315. (Thermal escape)
Venus

- Venus has slightly weaker gravity than Earth.
- The temperature on Venus is ________ than Earth.
- Is it easier to hold onto an atmosphere on Venus or Earth?
- Venus’s atmosphere is 92x thicker than Earth’s.
- Something for you to ponder.

Summary

1. Defining Force
2. Falling around
3. Weightlessness
4. Newton’s 3\textsuperscript{rd} law of Forces (not motion)
5. Newton’s 1\textsuperscript{st} & 2\textsuperscript{nd} laws of motion
7. Falling down – equal accelerations
8. Escaping = not coming back.
   - NOT escaping gravity!