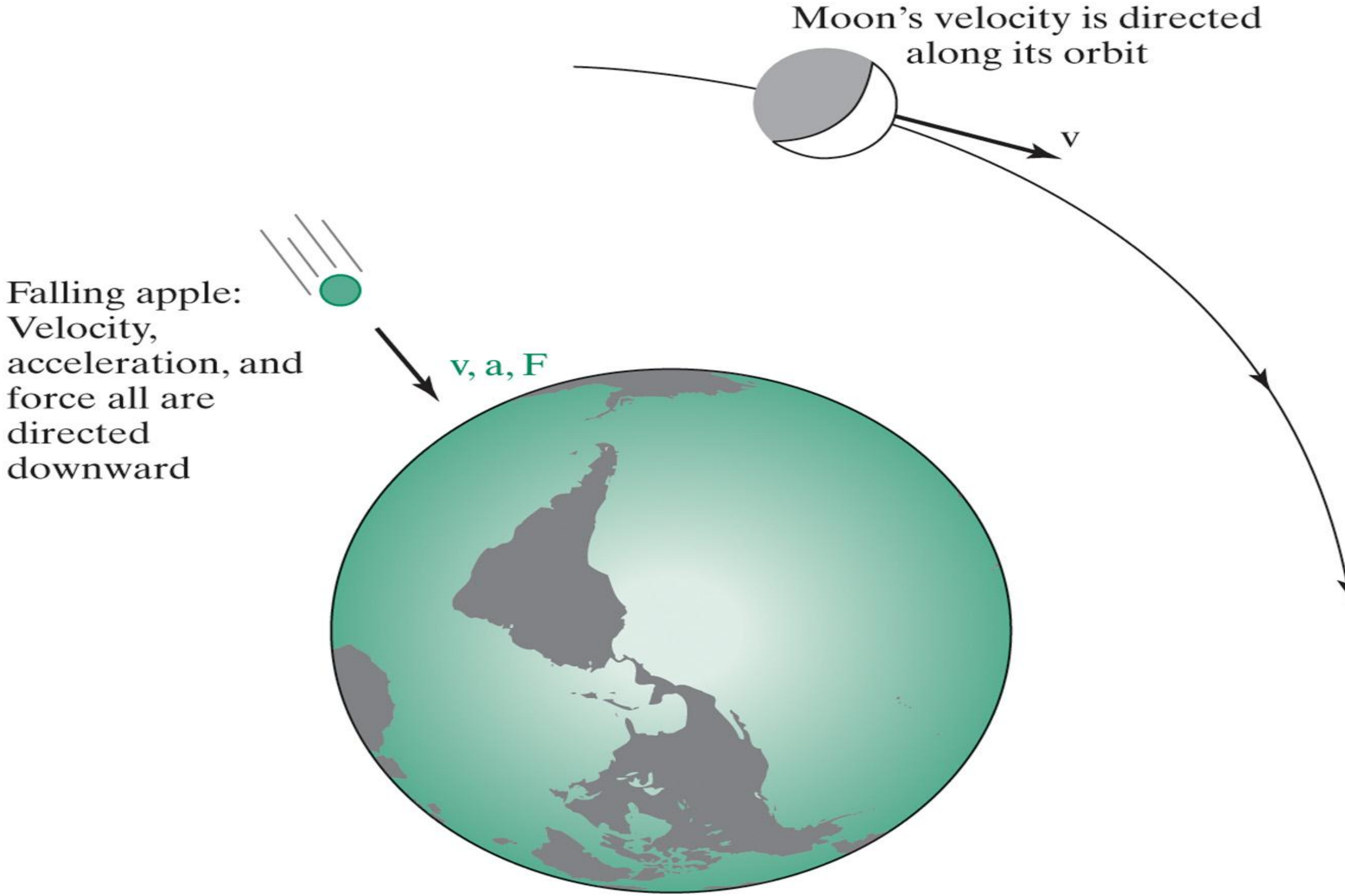
Chapter 5: Newtonian Gravity

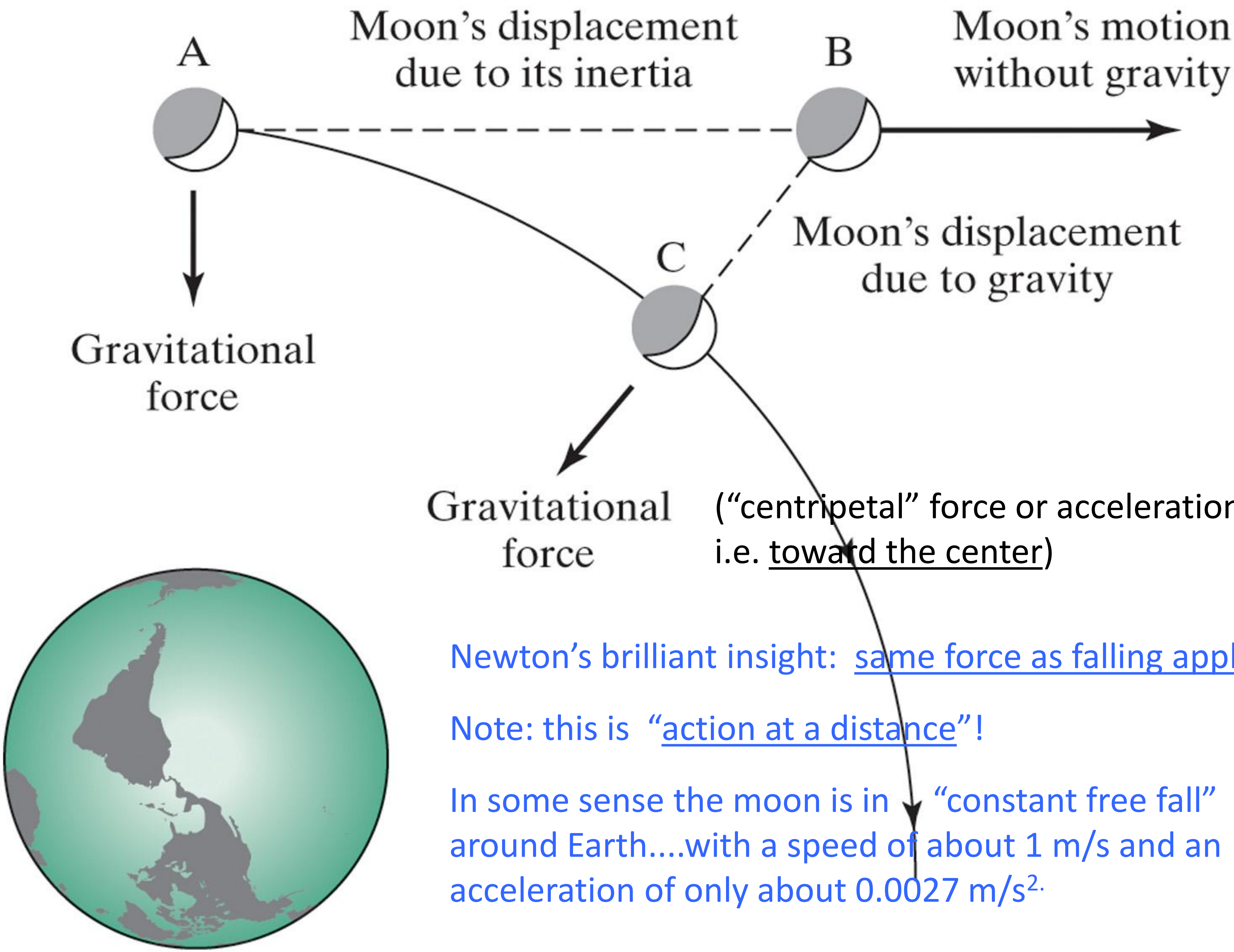
Outline of today's class (apart from quizzes):

Brief Review of Newtonian Gravity & Examples

More review for exam # 1 (to cover chapters 2 – 5, to the extent covered in class, excluding momentum)

Newton's Gravity, a.k.a. "the apple and the moon", one of nature's fundamental forces (only 4!!)



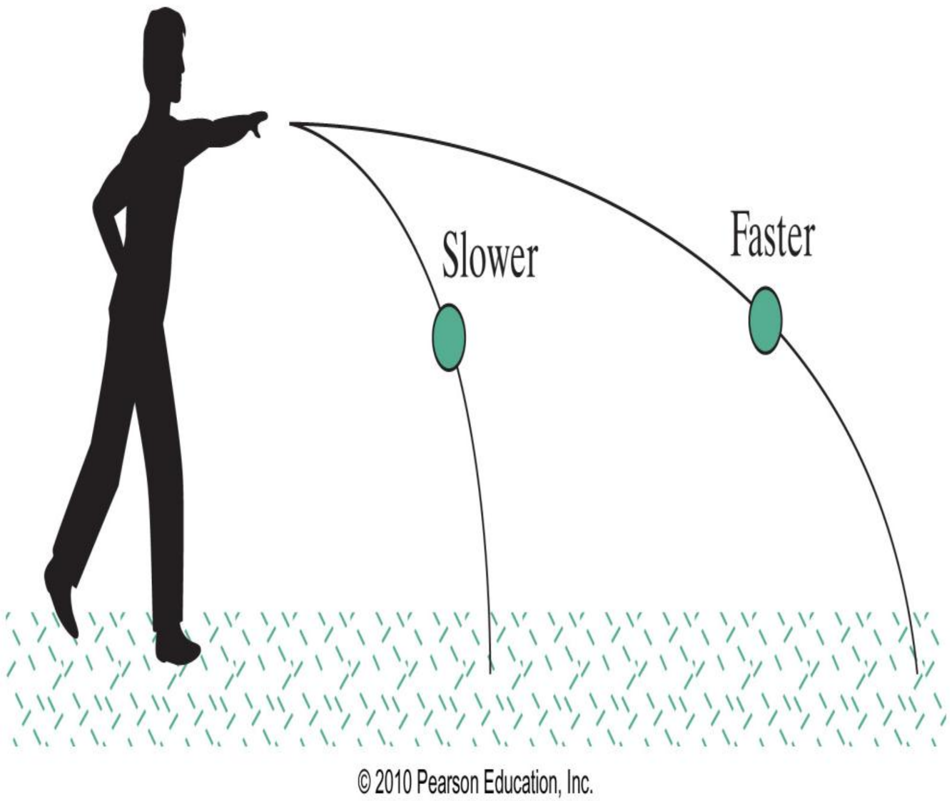


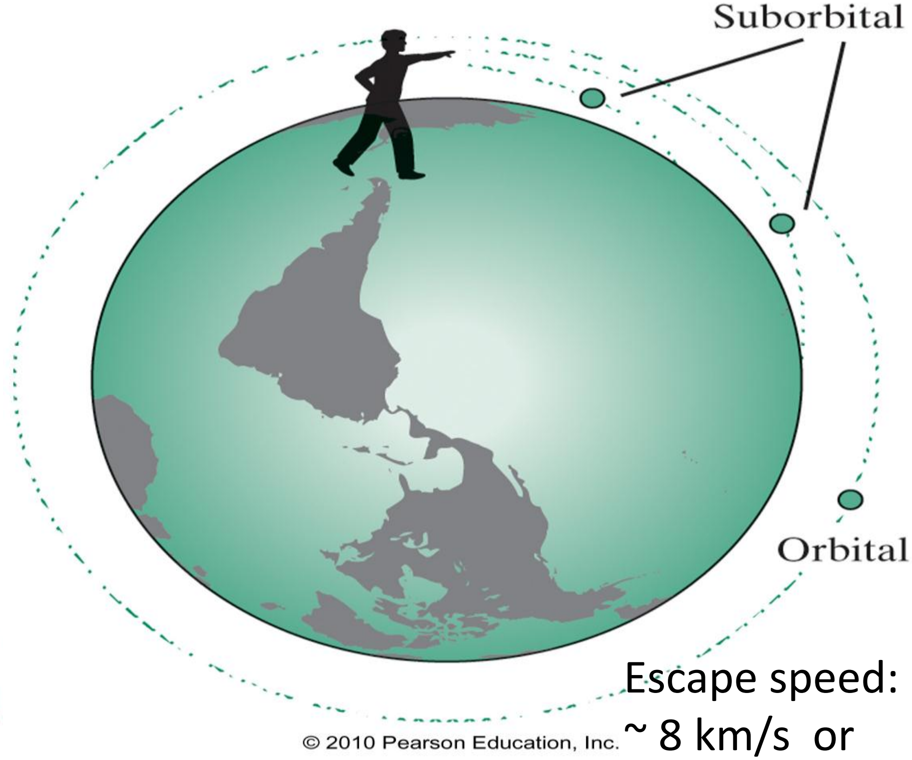
("centripetal" force or acceleration, i.e. <u>toward the center</u>)

Newton's brilliant insight: <u>same force as falling apple</u>!

Note: this is "<u>action at a distance</u>"!

In some sense the moon is in "constant free fall" around Earth....with a speed of about 1 m/s and an acceleration of only about 0.0027 m/s^2.





Escape speed:
~ 8 km/s or
~29,000 km/hr

Important: make sure Concept Checks 1 – 4 are clear!

<u>Quiz # 29</u>: When you crumple a sheet of paper into a tight ball, does its mass (weight) change?

(a) yes (yes) (b) yes (no) (c) no (yes) (d) no (no)

Quiz # 30: Do you exert a gravitational force on Earth? If yes, how large is it and in what direction?

(a) no
(b) yes, equal to your mass and directed downward
(c) yes, equal to your weight and directed upward
(d) yes, equal to your weight and directed downward
(e) yes, equal to your mass and directed upward

Newton's Theory of Gravity

Between any two objects there is an attractive force that is proportional to the product of the two objects' masses and proportional to the inverse of the square of the distance between them:

$$\text{gravitational force} \propto \frac{(\text{mass of 1st object}) \times (\text{mass of 2nd object})}{\text{square of distance between them}}$$

$$F \propto \frac{m_1 \times m_2}{d^2}$$

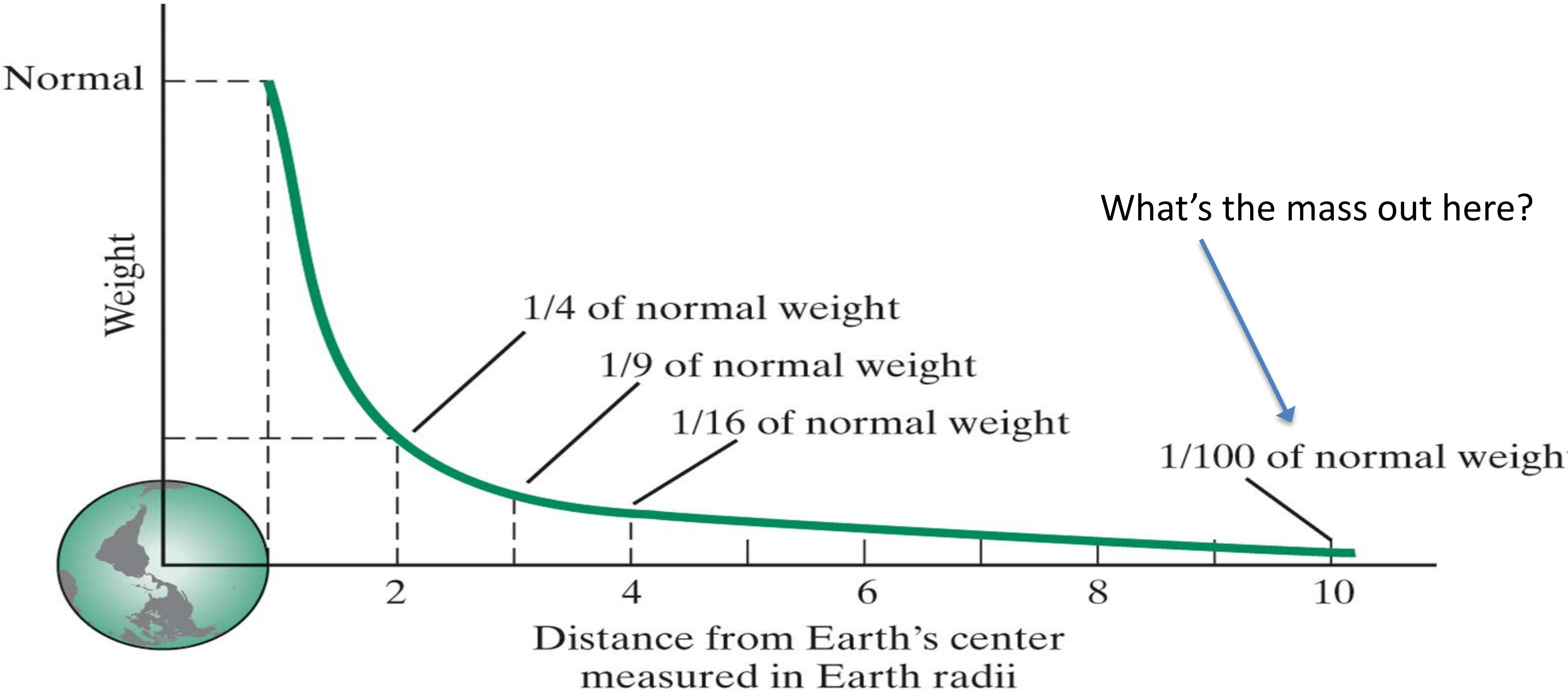
If mass is expressed in kilograms, distance in meters, and force in newtons, this proportionality becomes

$$\boxed{F = 6.7 \times 10^{-11} \frac{m_1 \times m_2}{d^2}}$$

6.7×10^{-11} Nm^2/kg^2 = "G"

- $F_{gravity}$ experienced by <u>*any* two masses</u>, anywhere in the universe.
- <u>Always attractive</u>, and can't be shielded against.
- One of <u>4 fundamental forces</u>, decreases rapidly with distance.
- Very weak for "ordinary" masses, but crucial for astronomy.

Worried about your weight? (Weight being what?)



Please never forget: weight & mass are *not* the same! But at a given location they are proportional to each other. Why?

Hint: Newton's 2nd! $W = m \times g$

How is W(eight) related to $F_{gravity}$? Supposed to be the same, right?

$W = m \times g$ ←→ $F_{gravity} = G \times m_1 \times m_2 / d^2$

$m_1 \rightarrow m_{Earth}$ and $m_2 \rightarrow m$, and what about d ?

$d = R_{Earth}$ (radius of Earth), so that $g = G \times m_E / R_E^2$ = a constant

<u>Quiz # 31</u>: Estimate $F_{gravity}$ between two cars (say 1.5 metric tons each), parked 4 m apart. $G = 6.7 \times 10^{-11}$ (when using kg, m, N)

(a) about 1 N

(b) about 10^{-5} N

(c) about 10^{-11} N

(d) about 10^{-8} N

And in contrast (problem 5): 1 cm^3 water (= 1 gram) on a neutron star weighs about 2.7 billion (10^9) N !!!


"Pillars of (Star) Creation"
(Picture from the Hubble Space Telescope)


Carina Nebula
(also from Hubble Space
Telescope)

Stellar Demise in “Bug” Nebula

The “butterfly” stretches for more than 2 light-years, which is about half the distance from the Sun to the nearest star, Alpha Centauri.

Supernova 1987a: power of ~10^8 suns for several months!!
~163,000 light years away - when did it actually go off?

Very exciting, recent event, a supernova “only” 21 million light-years away:

www.youtube.com/watch?v=CJIaC7DU0mw&feature=relmfu

Notice (sections 5.2 – 5.4): while $F_{gravity}$ is *very* small for everyday objects (Quiz # 31), it is the dominant, the most important force in astronomy/cosmology & for the development of our universe…… …..well, perhaps until the fairly recent discovery of “*dark energy*” (section 11.6)?

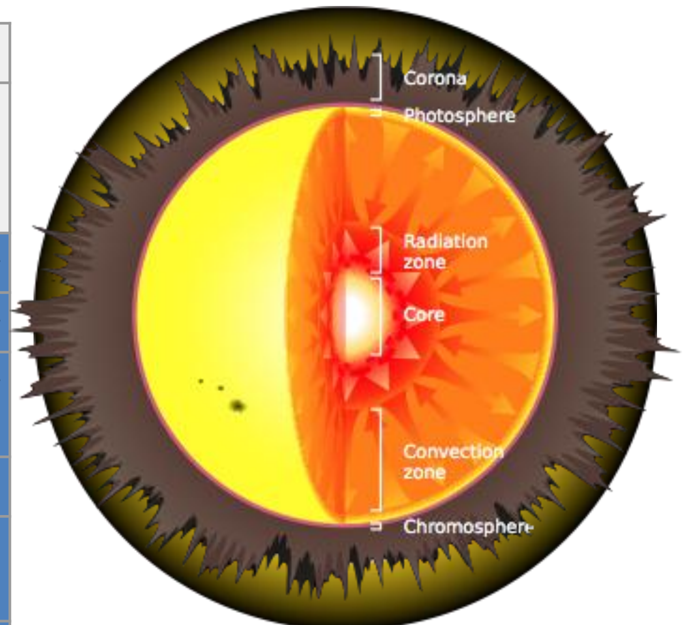
In particular: $F_{gravity}$ responsible for *birth & death* of stars, planets, planetary systems (like our own solar system), galaxies, clusters of galaxies, etc.

This includes the stunning & amazing astrophysical consequences of gravitational collapse, i.e. white dwarfs, supernova explosions, neutron stars, and black holes.

Note: a star’s mass determines its ultimate fate.

Stellar Evolution

Process	Main fuel	Main products	25 M$_\odot$ star		
			Temperature (Kelvin)	Density (g/cm^3)	Duration
hydrogen burning	hydrogen	helium	7×10^7	10	10^7 years
triple-alpha process	helium	carbon, oxygen	2×10^8	2000	10^6 years
carbon burning process	carbon	Ne, Na, Mg, Al	8×10^8	10^6	10^3 years
neon burning process	neon	O, Mg	1.6×10^9	10^7	3 years
oxygen burning process	oxygen	Si, S, Ar, Ca	1.8×10^9	10^7	0.3 years
silicon burning process	silicon	nickel (decays into iron)	2.5×10^9	10^8	5 days



Wikipedia: Type II Supernova

Epilogue on the Newtonian worldview:

Characterized by *predictability & determinism*

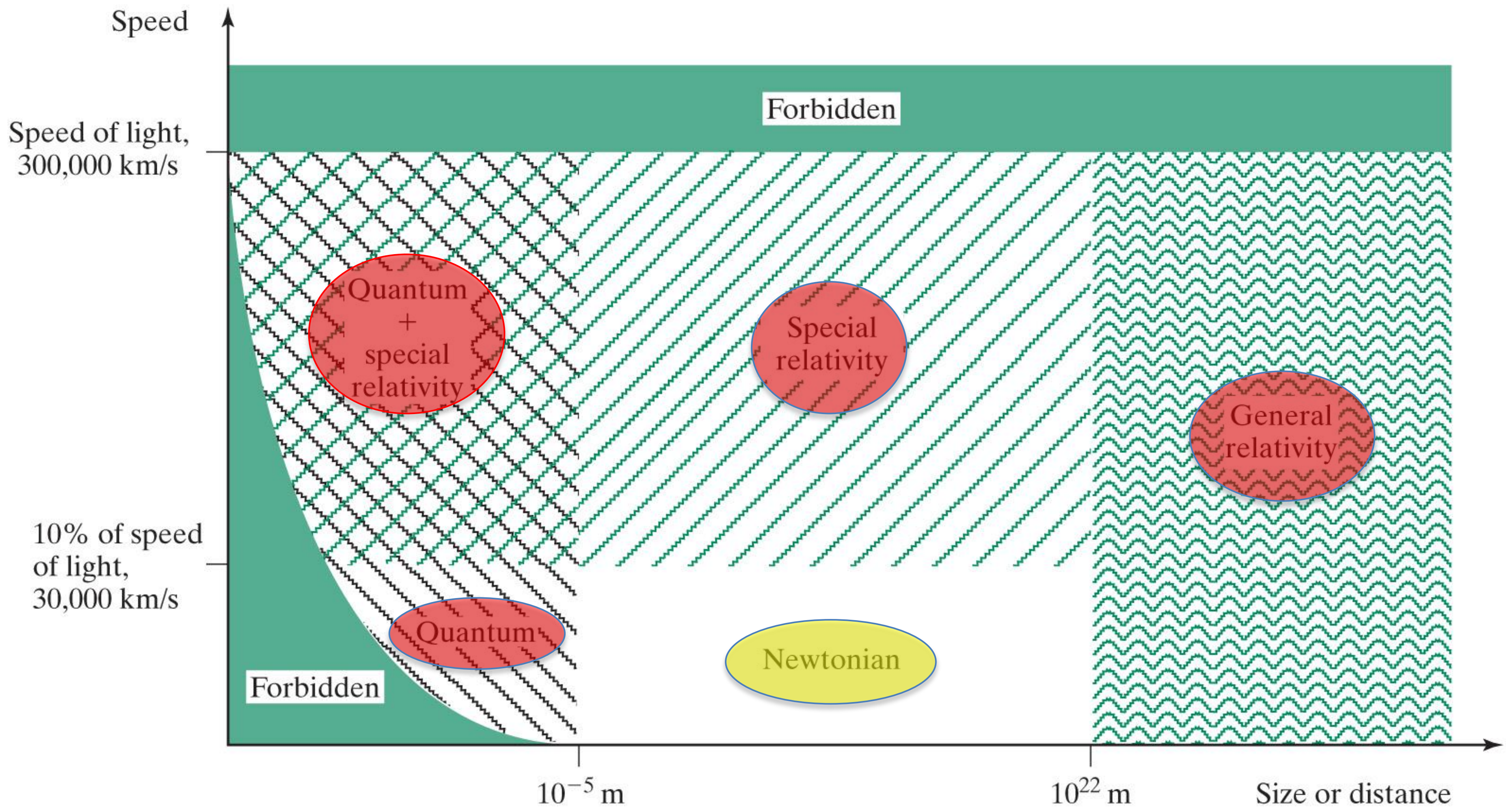
Example: given forces & initial conditions (positions, velocities, etc.) the future state of a system can (in principle at least) be calculated or predicted precisely.

Post-Newtonian worldview:

Physics revolutions of the early 20th century: Quantum Mechanics (or Quantum Physics) and Relativity (Special & General)

In QM determinism is lost, at least to some extent. In some cases only probabilities can be calculated. *Very* uncomfortable for our intuition….”God does not play dice with the world! (Einstein)….to this day serious discussions about the philosophical implications of QM.

Limitations/breakdowns (at least approximate) to/of Newtonian physics (diagram below only approximate & schematic!):



C.E. 10: No, because $F_{gravity}$ diminishes like $1/\text{distance}^2$.

C.E. 28: Geosynchronous orbits of communications satellites – their orbital period?

A: 24 hours

<u>Quiz # 32</u>: Giant Jupiter has a mass of 300 m_{Earth}. Therefore an object's weight on Jupiter should be 300 times its weight on Earth. But actual weight on Jupiter is only 3 times weight on Earth. Why?

(a) Something happens to the object's mass on Jupiter.
(b) Jupiter's radius is 10 times Earth's radius.
(c) Jupiter's radius is 100 times Earth's radius.
(d) none of the above

Returning to the weakness of gravity:

CONCEPT CHECK 5 Suppose that you were in distant space, far from all planets and stars, and you placed an apple and a book at rest in front of you, separated by about 1 m, and then moved some distance away in order to observe the apple and book without influencing them. The apple and the book would then (a) very slowly accelerate toward each other; (b) very rapidly accelerate toward each other; (c) move toward each other without accelerating; (d) remain at rest; (e) head for the beach.

A: (a), but how slowly?

They would collide in ~26 hours !!

<u>Quiz # 33</u>: You’re in a plane that dives down from very high altitude. During that dive,

(a) your weight & mass remain normal, i.e. the same as on Earth.

(b) both decrease.

(c) weight remains normal, but mass decreases.

(d) both increase.

(e) weight increases, but mass remains as on Earth.

Yet more review for exam 1:

1) Projectile motion – something thrown horizontally: what forces are acting?

2) Develop a feel for the magnitude of 1 N – weight of your book?

3) Motion of the moon (or planetary motion): force, and therefore acceleration towards ? What force?

…the center – “centripetal”…..What if force would suddenly stop?

4) Worth remembering: gravity on our moon ~1/6 of g on Earth

5) “Internal” friction within a car vs. “rolling resistance” – don’t confuse: internal friction costs energy/power, but is <u>*not*</u> a (n external) force <u>*on*</u> the car.