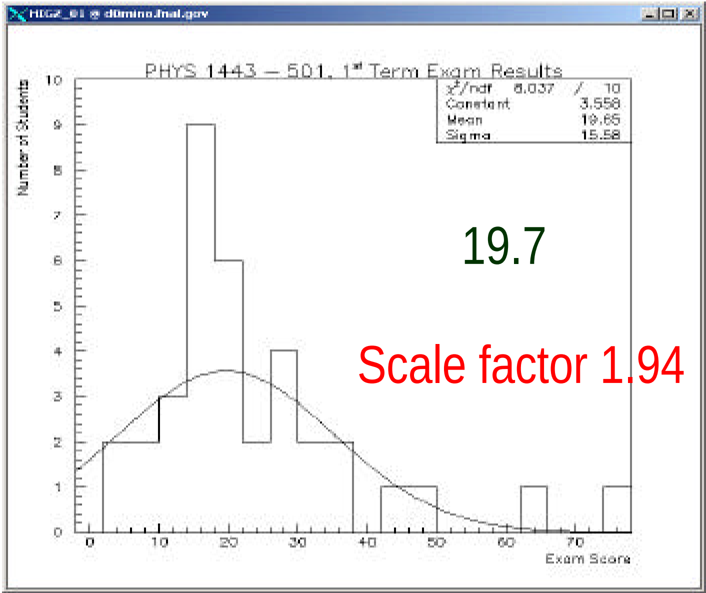
1443-501 Spring 2002
Lecture #20

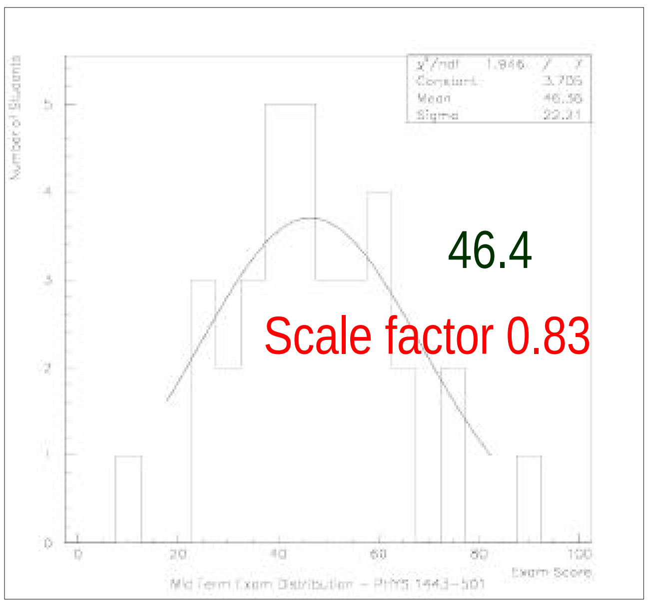
Dr. Jaehoon Yu

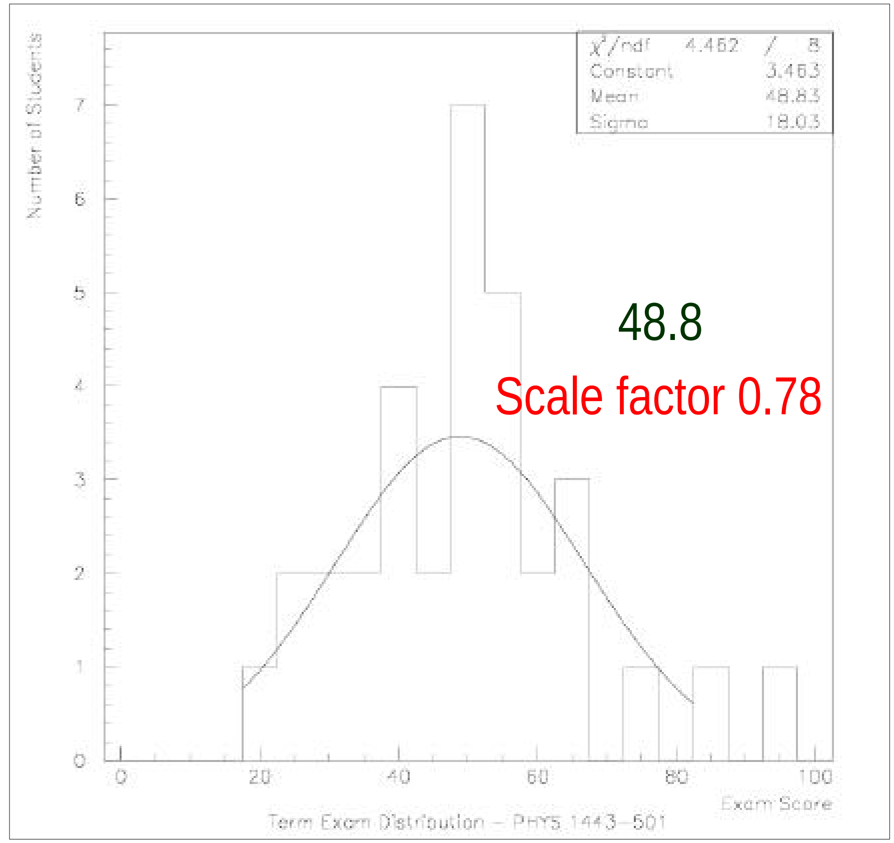
1. Exam Results & Solutions
2. Newton's Law of Universal Gravitation
3. Free Fall Acceleration and Gravitational Force

No Homework Assignment today!!

2nd Term Distributions







You certainly have improved, especially given the fact that you all thought the exam was tough. There are finals (30%) and the lab (20%). Just keep it up. You will make it.

Overall average: 38.3

1st Term Exam Results	Sacled 1st term	Mid-term Exam, Mar. 13, 2002	Scaled Mid-term	2nd Term Exam Results	Scaled 2nd term
27	52.38	62	51.46	50	39.5
15	29.1	9	7.47	25	19.75
4	7.76	26	21.58	29	22.91
31	60.14	60	49.8	52	41.08
15	29.1	46	38.18	48	37.92
21	40.74	75	62.25	55	43.45
13	25.22	43	35.69	58	45.82
18	34.92	50	41.5	53	41.87
49.3	95.642	77	63.91	63	49.77
17	32.98	28	23.24	27	21.33
20	38.8	55	45.65	48	37.92
8	15.52	0	0	0	0
0	0	0	0	0	0
14	27.16	53	43.99	41	32.39
28.5	55.29	42	34.86	55	43.45
17	32.98	47.5	39.425	50	39.5
17	32.98	50	41.5	43	33.97
28.8	55.872	65	53.95	56	44.24
74	143.56	90	74.7	96	75.84
24	46.56	25	20.75	0	0
5	9.7	23	19.09	18	14.22
34.8	67.512	59	48.97	77	60.83
20	38.8	34	28.22	0	0
64	124.16	56	46.48	83	65.57
15	29.1	40	33.2	35	27.65
13	25.22	38	31.54	29	22.91
13	25.22	28	23.24	41	32.39
29	56.26	42	34.86	63	49.77
7	13.58	0	0	0	0
22	42.68	63	52.29	52	41.08
14	27.16	0	0	0	0
33	64.02	36	29.88	50	39.5
21	40.74	35	29.05	40	31.6
42	81.48	38.5	31.955	45	35.55
18	34.92	45	37.35	39	30.81
35	67.9	46	38.18	67	52.93
18	34.92	46	38.18	37	29.23
17	32.98	59	48.97	56	44.24
19.7	38.218	46.8	38.844	47.9	37.841

Newton's Law of Universal Gravitation

People have been very curious about the stars in the sky, making observations for a long time. But the data people collected have not been explained until Newton has discovered the law of gravitation.

Every particle in the Universe attracts every other particle with a force that is directly ***proportional to the product of their masses*** *and* ***inversely proportional to the square of the distance*** *between them.*

How would you write this principle mathematically?

$$F_g \propto \frac{m_1 m_2}{r_{12}^2}$$

With G

$$F_g = G\frac{m_1 m_2}{r_{12}^2}$$

G is the universal gravitational constant, and its value is

$$G = 6.673 \times 10^{-11}$$

Unit?

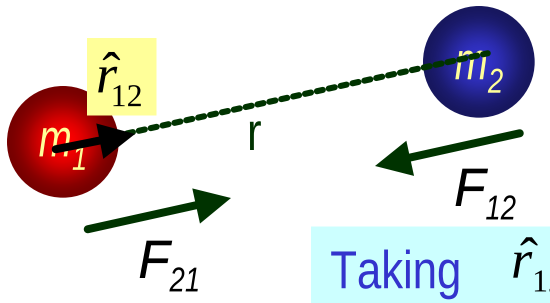
$$N \cdot m^2 / kg^2$$

This constant is not given by the theory but must be measured by experiment.

This form of forces is known as an inverse-square law, because the magnitude of the force is inversely proportional to the square of the distances between the objects.

More on Law of Universal Gravitation

Consider two particles exerting gravitational forces to each other.



Two objects exert gravitational force on each other following Newton's 3rd law.

Taking $\hat{r}_{12}$ as the unit vector, we can write the force m_2 experiences as

$$\vec{F}_{12} = -G\frac{m_1 m_2}{r^2}\hat{r}_{12}$$

What do you think the negative sign mean?

It means that the force exerted on the particle 2 by particle 1 is attractive force, pulling #2 toward #1.

Gravitational force is a field force: Force act on object without physical contact between the objects at all times, independent of medium between them.

The gravitational force exerted by a finite size, spherically symmetric mass distribution on a particle outside the distribution is the same as if the entire mass of the distributions was concentrated at the center.

How do you think the gravitational force on the surface of the earth look?

$$F_g = G\frac{M_E m}{R_E^2}$$

Free Fall Acceleration & Gravitational Force

Weight of an object with mass *m* is *mg*. Using the force exerting on a particle of mass m on the surface of the Earth, one can get

$$mg = G\frac{M_E m}{R_E^2}$$

$$g = G\frac{M_E}{R_E^2}$$

What would the gravitational acceleration be if the object is at an altitude h above the surface of the Earth?

$$F_g = mg' = G\frac{M_E m}{r} = G\frac{M_E m}{(R_E + h)^2}$$

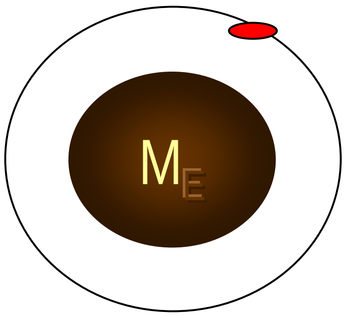
$$g' = G\frac{M_E}{(R_E + h)^2}$$

What do these tell us about the gravitational acceleration?

- The gravitational acceleration is independent of the mass of the object
- The gravitational acceleration decreases as the altitude increases
- If the distance from the surface of the Earth gets infinitely large, the weight of the object approaches 0.

Example 14.2

The international space station is designed to operate at an altitude of 350km. When completed, it will have a weight (measured on the surface of the Earth) of 4.22×10^6N. What is its weight when in its orbit?



The total weight of the station on the surface of the Earth is

$$F_E = mg = G\frac{M_E m}{R_E^{\ 2}} = 4.22 \times 10^6\, N$$

Since the orbit is at 350km above the surface of the Earth, the gravitational force at that height is

$$F_O = mg' = G\frac{M_E m}{\left(R_E + h\right)^2} = \frac{R_E^2}{\left(R_E + h\right)^2} F_E$$

Therefore the weight in the orbit is

$$F_O = \frac{R_E^2}{\left(R_E + h\right)^2} F_E = \frac{\left(6.37 \times 10^6\right)^2}{\left(6.37 \times 10^6 + 3.50 \times 10^5\right)^2} \times 4.22 \times 10^6 = 3.80 \times 10^6\, N$$

Example 14.3

Using the fact that g=9.80m/s^2 at the Earth's surface, find the average density of the Earth.

Since the gravitational acceleration is

$$g = G\frac{M_E}{R_E^{\ 2}} = 6.67\times10^{-11}\frac{M_E}{R_E^{\ 2}}$$

So the mass of the Earth is

$$M_E = \frac{R_E^{\ 2}g}{G}$$

Therefore the density of the Earth is

$$r = \frac{M_E}{V_E} = \frac{\frac{R_E^{\ 2}g}{G}}{\frac{4p}{3}R_E^{\ 3}} = \frac{3g}{4pGR_E}$$

$$= \frac{3\times9.80}{4p\times6.67\times10^{-11}\times6.37\times10^{6}} = 5.50\times10^{3}kg/m^{3}$$