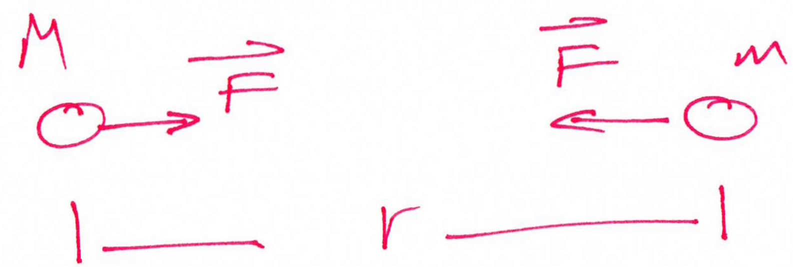
Newton's Fourth Law or Newton's Law of Gravitation – Two particles of mass M and m are mutually attracted with equal and opposite forces $\vec{F}$ and $-\vec{F}$ according to the following relationship:

$$\vec{F} = G\frac{Mm}{r^2}$$



where

r is the distance between the two particles

G is the universal constant of gravitation

$$G = 6.67 \times 10^{-11}\ \text{m}^3 / (\text{kg s}^2)\ [\text{SI}]$$

or

$$G = 3.44 \times 10^{-8}\ \text{ft}^4 / (\text{lb s}^4)\ [\text{US Customary}]$$

WARNING: NEWTON'S LAW OF GRAVITATION IS **NOT** DERIVED FROM NEWTON'S SECOND LAW -- FAILURE TO INTERNALIZE THIS SIMPLE **TRUTH** WILL RESULT IN A COMPLETE LACK OF UNDERSTANDING OF FUNDAMENTAL NEWTONIAN MECHANICS.

GRAVITY MANIFESTS ITSELF AS FORCE –
NOT ACCELERATON.

Planet	***Mass (kg)***	***Radius (m)***	***Distance from Sun (km)***
Mercury	3.30 x 10^23	2,440,000	5.79×10^7
Venus	4.87 x 10^24	6,051,000	1.082×10^8
Earth	5.97 x 10^24	6,378,000	1.496×10^8
Mars	6.42 x 10^23	3,397,000	2.279×10^8
Jupiter	1.90 x 10^27	71,492,000	7.783×10^8
Saturn	5.69 x 10^26	60,268,000	1.426×10^9
Uranus	8.66 x 10^25	25,559,000	2.871×10^9
Neptune	1.03 x 10^26	24,764,000	4.497×10^9
Pluto	1.31 x 10^22	1,160,000	5.914×10^9

	Mass (kg)	***Radius (m)***	***Distance from Earth (km)***
Moon	7.35 x 10^22	1,738,000	384,403

$G = 3.439 \times 10^{-8}\ ft^4/(lb\ s^4)$ or $G = 6.673 \times 10^{-11}\ m^3/(kg\ s^2)$

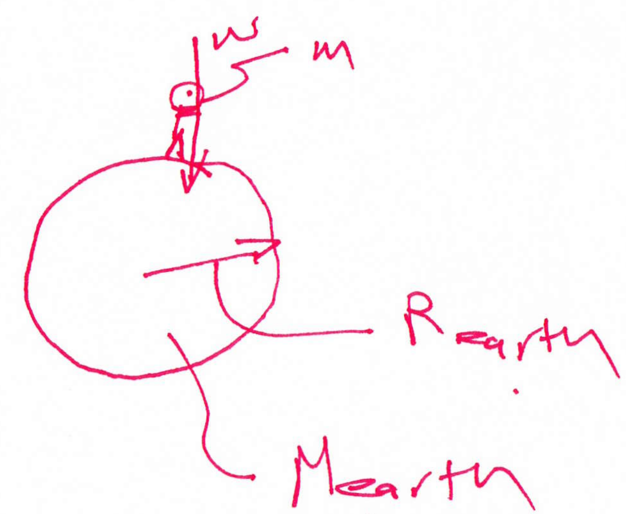
Use of Newton's Law of Gravitation on Earth

In the special case of the force of gravity between the earth and a particle (of mass m) located on or near the surface of the earth, Newton's Fourth law is frequently used to express the effect of gravity on the particle, or the weight, W, of the particle as follows:

$$W = m\,g$$

where

g is the gravitational constant on earth as follows:



$$g = \frac{GM}{R^2}$$

where G is the universal constant of gravitation, M is the mass of the earth, and R is the radius of the earth.

Gravitational Constants on Earth:

$$g = 9.81 \text{ m / s}^2$$

or

$$g = 32.2 \text{ ft / s}^2$$

SECOND WARNING – THESE VALUES of g ARE CONSTANTS – THEY ARE NOT ACCELERATIONS!!!

Units Commonly Used in Mechanics Problems

length -- ft, in, m, mm ~~cm~~

time -- sec, min, hour,

force -- lbf, kips (1000 lbs, kilo pound), N, kN

mass Kg, slugs.

Consistent Units

Mechanics problems are generally stated in terms of consistent units.

This means that the above four units (length, time, mass, and force) must be selected in such a way that they are dimensionally consistent with Newton's second law.

$$\vec{F} = m\vec{a}$$

$$F = m\frac{L}{t^2} \qquad m = \frac{t^2}{L}F \qquad \text{lb}$$

Generally, the desired units for length and time are established based upon the preference of the engineer.

Then, a decision is made to specify the desired units to represent either mass or force based upon the preference of the engineer.

Absolute System of Units

SI.

If the units for mass are specified, then the units of force must be dimensionally consistent with Newton's second law. This system of units is generally called an absolute system of units.

Gravitational System of Units

US.

If the units for force are specified, then the units of mass must be dimensionally consistent with Newton's second law. This system of units is generally called a gravitational system of units.

Beer and Johnston 1962/Beer, Johnston, Mazurek, and Eisenberg 2013

Consistent Set of Units

Dimensions	British System	Metric System
	Absolute	Absolute
Length	foot (ft)	meter (m)
Mass	pound (lbm)	kilogram (kg)
Time	second (s)	second (s)
Force, F = ma	Poundal (lbm-ft/s^2)	Newton (kg-m/s^2)
	Gravitational	Gravitational
Length	foot (ft)	meter (m)
Force	pound (lbf)	kilogram (kg)
Time	second (s)	second (s)
Mass, m = F/a	slug (lbf-sec^2/ft)	kg-sec^2/m

Inconsistent Set of Units

$$\vec{F} = m\,\vec{a}$$

$$\vec{F} = k\,m\,\vec{a}$$

where k is an arbitrary constant.

lbm

g

lbm

lbf

Common Consistent Units for CVEN 221		
	SI	**US Customary**
time	Second (s)	Second (s)
length	Meter (m)	feet (ft)
mass	Kilogram (kg)	slug
force	Newton (N)	Pounds (lbs)

Common Unit Conversions for CVEN 221												
Length					**Mass**				**Force**			
	m	**in**	**ft**	**mi**		**kg**	**slug**			**N**	**lb**	**k**
1 m =	1.0	39.37	3.281	6.214e-4	**1 kg =**	1.0	6.852e-2		**1 N =**	1.0	0.2248	2.248e-4
1 in =	2.540e-2	1.0	8.333e-2	1.578e-5	**1 slug =**	14.59	1.0		**1 lb =**	4.448	1.0	1.0e-3
1 ft =	0.3048	12.00	1.0	1.894e-4					**1 k =**	4448	1000	1.0
1 mi =	1609	6.336e4	5280	1.0								