

April 19, Week 13

Today: Chapter 13, Gravity

Homework Assignment #10 - Due Today.

Mastering Physics: 7 problems from chapter 9

Written Question: 10.86

From now on, Thursday office hours will be held in room 109 of Regener Hall

Exam #4, Next Friday, April 26

Practice Exam on Website.

Newton's Law of Gravitation

Newton's Law of Gravitation - Every object with mass exerts a gravitational force on every other object with mass.

Newton's Law of Gravitation

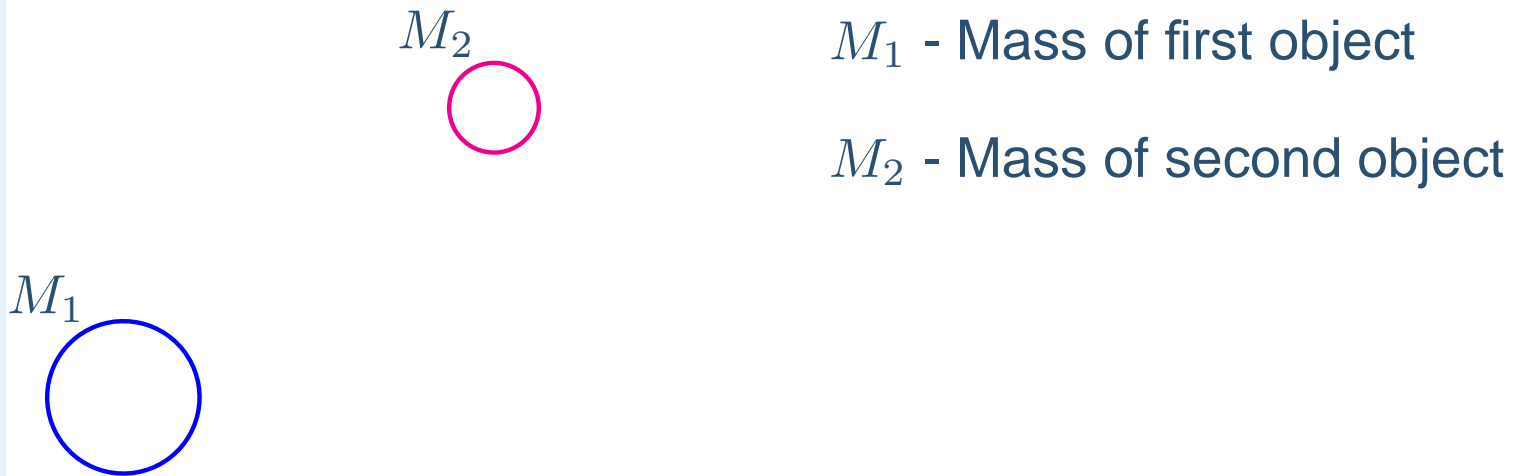
Newton's Law of Gravitation - Every object with mass exerts a gravitational force on every other object with mass.

The magnitude of this force is given by:

Newton's Law of Gravitation

Newton's Law of Gravitation - Every object with mass exerts a gravitational force on every other object with mass.

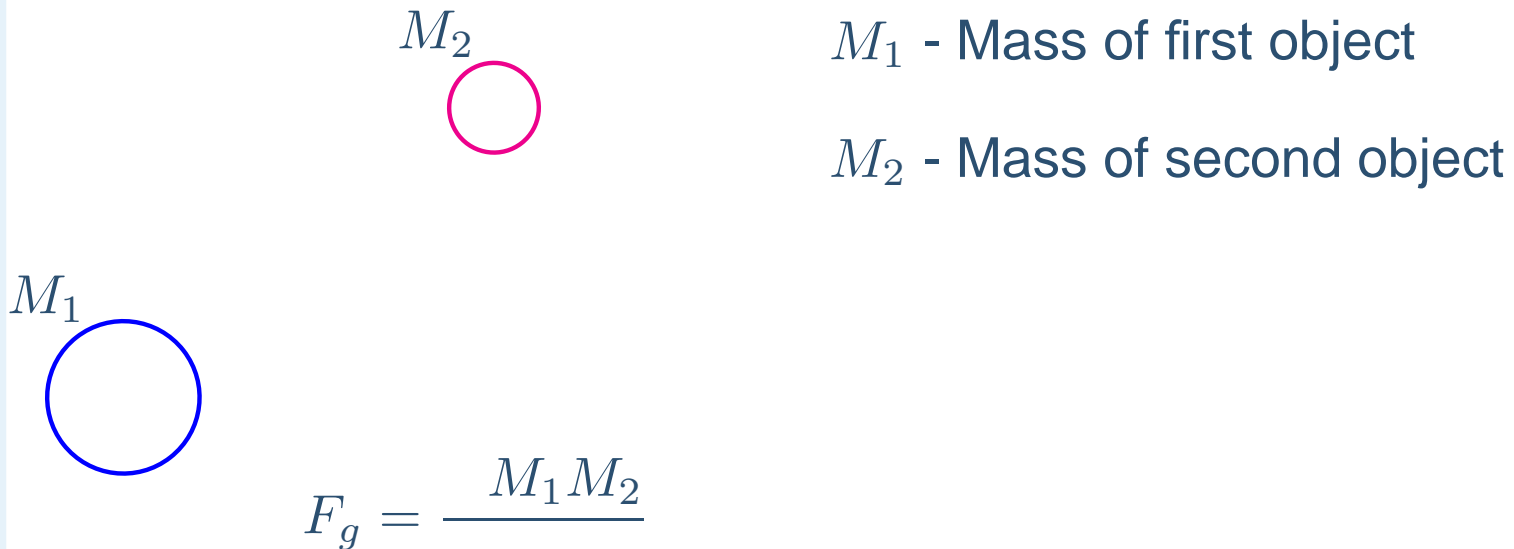
The magnitude of this force is given by:



Newton's Law of Gravitation

Newton's Law of Gravitation - Every object with mass exerts a gravitational force on every other object with mass.

The magnitude of this force is given by:



M_2

M_1 - Mass of first object

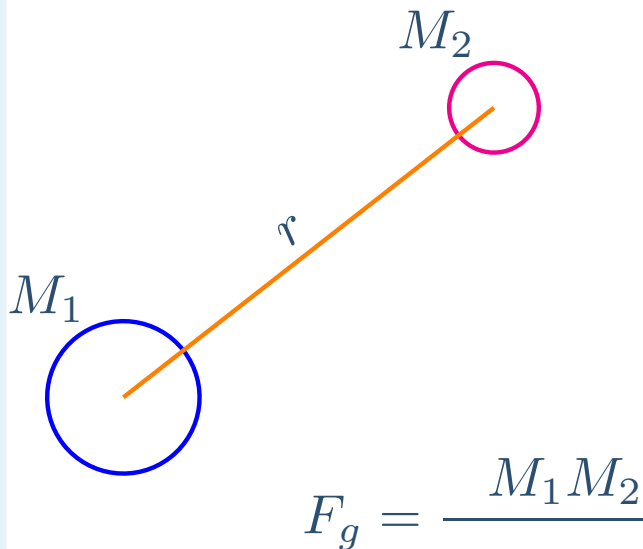
M_2 - Mass of second object

$$F_g = \frac{M_1 M_2}{r^2}$$

Newton's Law of Gravitation

Newton's Law of Gravitation - Every object with mass exerts a gravitational force on every other object with mass.

The magnitude of this force is given by:



M_1 - Mass of first object

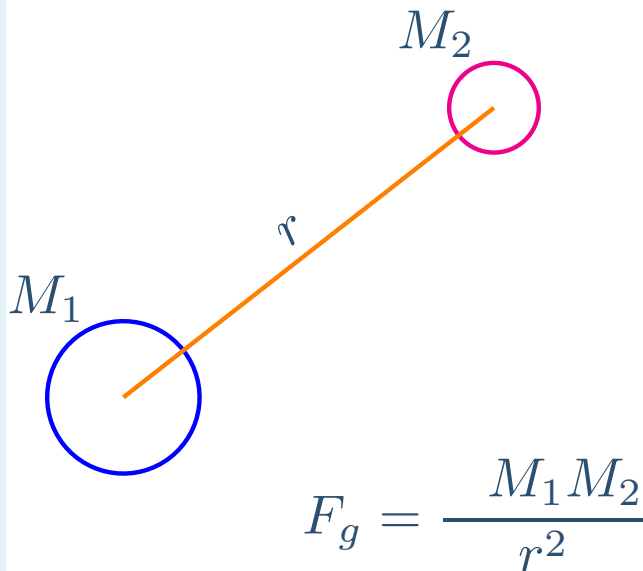
M_2 - Mass of second object

r - separation distance,
center-to-center for spherical objects

Newton's Law of Gravitation

Newton's Law of Gravitation - Every object with mass exerts a gravitational force on every other object with mass.

The magnitude of this force is given by:



M_1 - Mass of first object

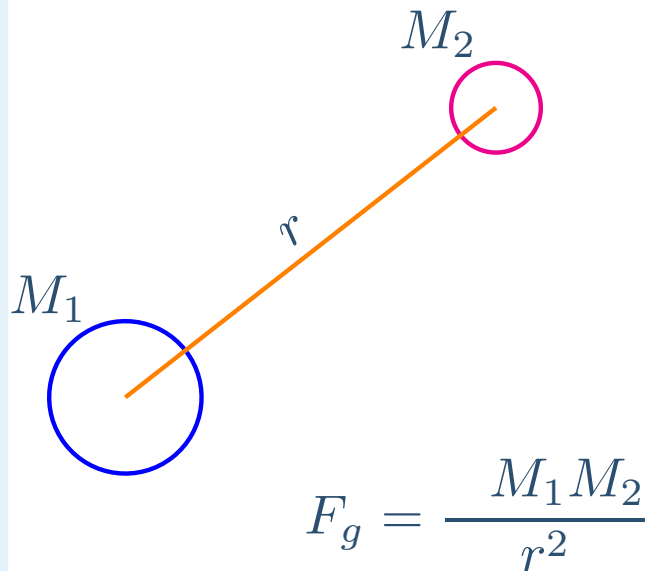
M_2 - Mass of second object

r - separation distance,
center-to-center for spherical objects

Newton's Law of Gravitation

Newton's Law of Gravitation - Every object with mass exerts a gravitational force on every other object with mass.

The magnitude of this force is given by:



Inverse square law

M_1 - Mass of first object

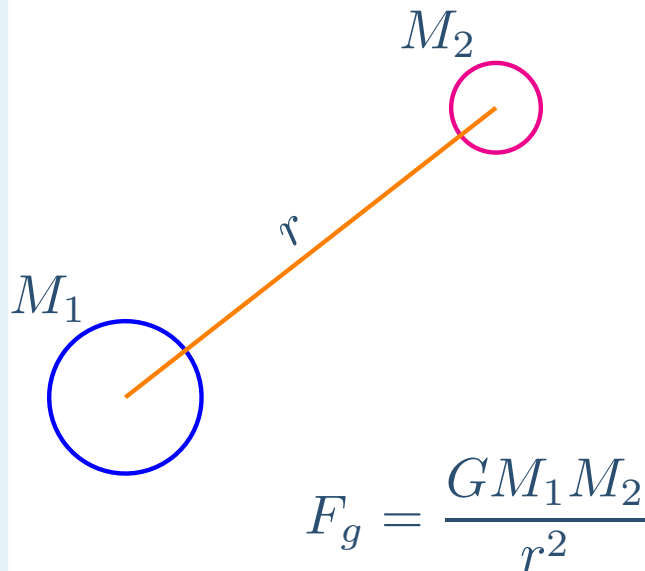
M_2 - Mass of second object

r - separation distance,
center-to-center for spherical objects

Newton's Law of Gravitation

Newton's Law of Gravitation - Every object with mass exerts a gravitational force on every other object with mass.

The magnitude of this force is given by:



Inverse square law

M_1 - Mass of first object

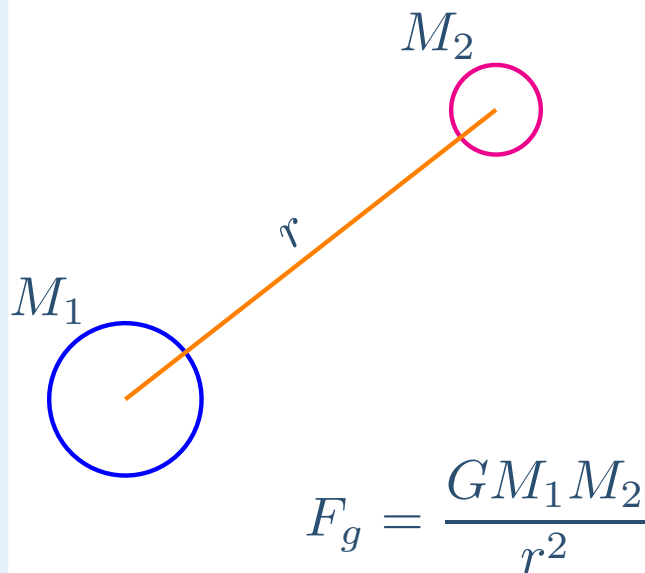
M_2 - Mass of second object

r - separation distance,
center-to-center for spherical objects

Newton's Law of Gravitation

Newton's Law of Gravitation - Every object with mass exerts a gravitational force on every other object with mass.

The magnitude of this force is given by:



Inverse square law

M_1 - Mass of first object

M_2 - Mass of second object

r - separation distance,
center-to-center for spherical objects

Universal Gravitational Constant:

$$G = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2 / \text{kg}^2$$

Inverse Square Law Exercise

When two masses are a distance r_1 apart from each other the gravitational force between them is 5 N . They are then moved to a new separation, r_2 , where the gravitational force between them is 10 N . What is the relation between r_1 and r_2 ?

Inverse Square Law Exercise

When two masses are a distance r_1 apart from each other the gravitational force between them is 5 N . They are then moved to a new separation, r_2 , where the gravitational force between them is 10 N . What is the relation between r_1 and r_2 ?

(a) $r_2 = r_1$

Inverse Square Law Exercise

When two masses are a distance r_1 apart from each other the gravitational force between them is 5 N . They are then moved to a new separation, r_2 , where the gravitational force between them is 10 N . What is the relation between r_1 and r_2 ?

(a) $r_2 = r_1$

(b) $r_2 = 2r_1$

Inverse Square Law Exercise

When two masses are a distance r_1 apart from each other the gravitational force between them is 5 N . They are then moved to a new separation, r_2 , where the gravitational force between them is 10 N . What is the relation between r_1 and r_2 ?

(a) $r_2 = r_1$

(b) $r_2 = 2 r_1$

(c) $r_2 = (\sqrt{2}) r_1 = (1.4) r_1$

Inverse Square Law Exercise

When two masses are a distance r_1 apart from each other the gravitational force between them is 5 N . They are then moved to a new separation, r_2 , where the gravitational force between them is 10 N . What is the relation between r_1 and r_2 ?

(a) $r_2 = r_1$

(b) $r_2 = 2 r_1$

(c) $r_2 = (\sqrt{2}) r_1 = (1.4) r_1$

(d) $r_2 = \left(\frac{1}{2}\right) r_1$

Inverse Square Law Exercise

When two masses are a distance r_1 apart from each other the gravitational force between them is 5 N . They are then moved to a new separation, r_2 , where the gravitational force between them is 10 N . What is the relation between r_1 and r_2 ?

(a) $r_2 = r_1$

(b) $r_2 = 2r_1$

(c) $r_2 = (\sqrt{2})r_1 = (1.4)r_1$

(d) $r_2 = \left(\frac{1}{2}\right)r_1$

(e) $r_2 = \left(\frac{1}{\sqrt{2}}\right)r_1 = (0.707)r_1$

Inverse Square Law Exercise

When two masses are a distance r_1 apart from each other the gravitational force between them is 5 N . They are then moved to a new separation, r_2 , where the gravitational force between them is 10 N . What is the relation between r_1 and r_2 ?

(a) $r_2 = r_1$

(b) $r_2 = 2r_1$

(c) $r_2 = (\sqrt{2})r_1 = (1.4)r_1$

(d) $r_2 = \left(\frac{1}{2}\right)r_1$

(e) $r_2 = \left(\frac{1}{\sqrt{2}}\right)r_1 = (0.707)r_1$

Inverse Square Law Exercise

When two masses are a distance r_1 apart from each other the gravitational force between them is 5 N . They are then moved to a new separation, r_2 , where the gravitational force between them is 10 N . What is the relation between r_1 and r_2 ?

(a) $r_2 = r_1$

(b) $r_2 = 2r_1$

(c) $r_2 = (\sqrt{2})r_1 = (1.4)r_1$

(d) $r_2 = \left(\frac{1}{2}\right)r_1$

(e) $r_2 = \left(\frac{1}{\sqrt{2}}\right)r_1 = (0.707)r_1$

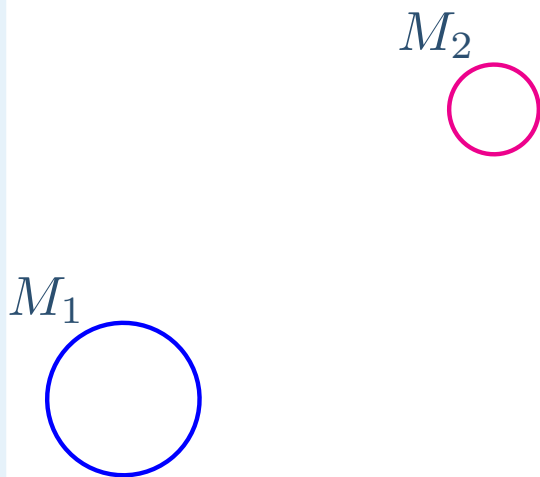
$$F_2 = \frac{GM_1M_2}{r_2^2} = \frac{GM_1M_2}{(r_1/\sqrt{2})^2} = \frac{GM_1M_2}{r_1^2/2} = \frac{GM_1M_2}{r_1^2} \times 2 = 2F_1$$

Direction

The gravitational force is an “attractive” force \Rightarrow each object feels a force towards the other.

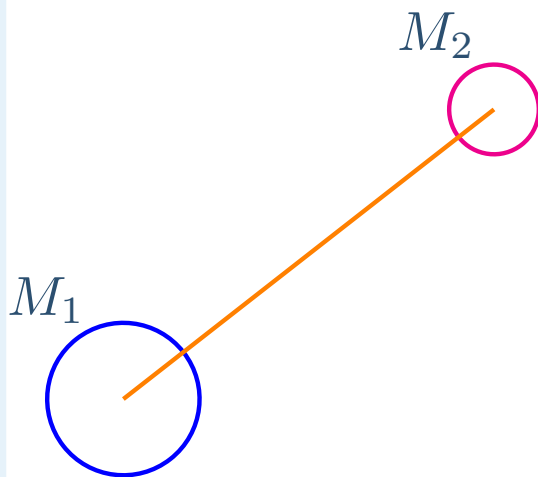
Direction

The gravitational force is an “attractive” force \Rightarrow each object feels a force towards the other.



Direction

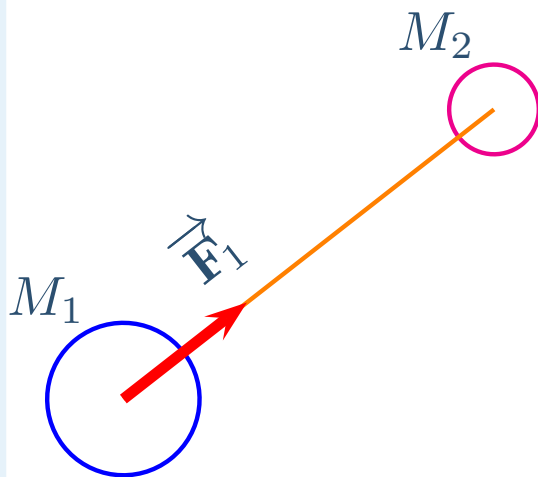
The gravitational force is an “attractive” force \Rightarrow each object feels a force towards the other.



Direction

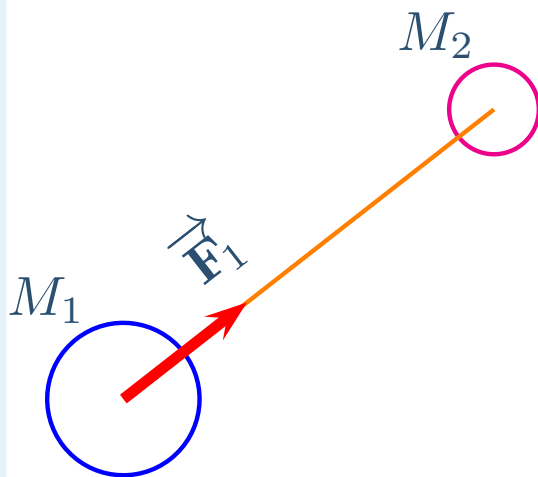
The gravitational force is an “attractive” force \Rightarrow each object feels a force towards the other.

\vec{F}_1 - Force on 1 due to 2



Direction

The gravitational force is an “attractive” force \Rightarrow each object feels a force towards the other.

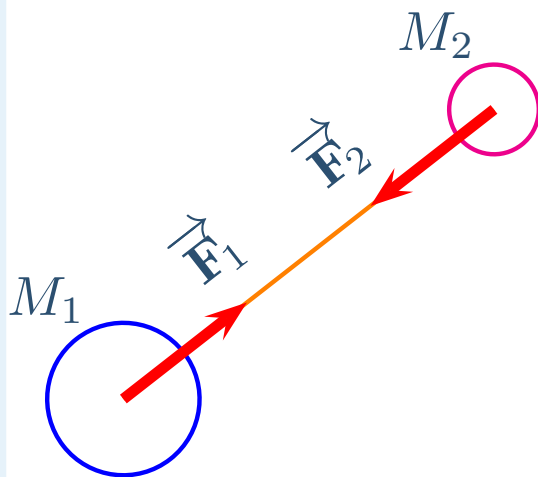


\vec{F}_1 - Force on 1 due to 2

\vec{F}_2 - Force on 2 due to 1

Direction

The gravitational force is an “attractive” force \Rightarrow each object feels a force towards the other.

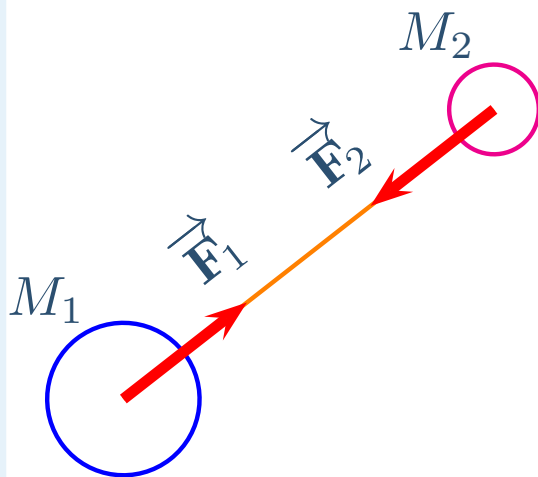


\vec{F}_1 - Force on 1 due to 2

\vec{F}_2 - Force on 2 due to 1

Direction

The gravitational force is an “attractive” force \Rightarrow each object feels a force towards the other.



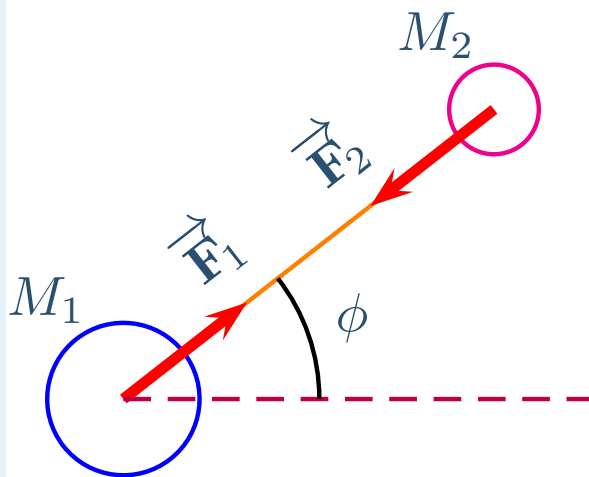
\vec{F}_1 - Force on 1 due to 2

\vec{F}_2 - Force on 2 due to 1

Geometry determines direction

Direction

The gravitational force is an “attractive” force \Rightarrow each object feels a force towards the other.



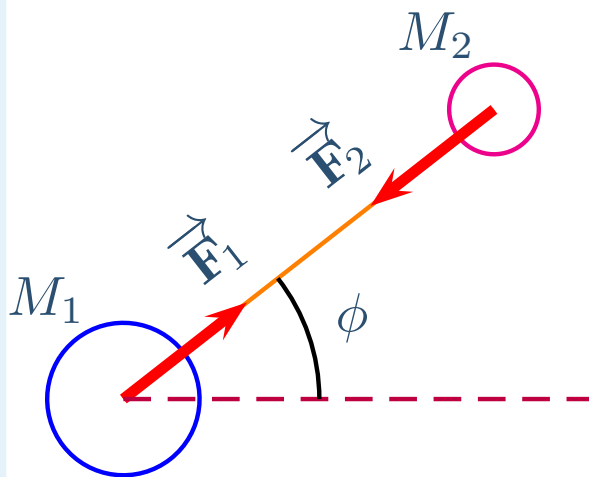
\vec{F}_1 - Force on 1 due to 2

\vec{F}_2 - Force on 2 due to 1

Geometry determines direction

Direction

The gravitational force is an “attractive” force \Rightarrow each object feels a force towards the other.

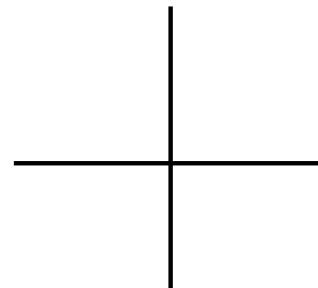


\vec{F}_1 - Force on 1 due to 2

\vec{F}_2 - Force on 2 due to 1

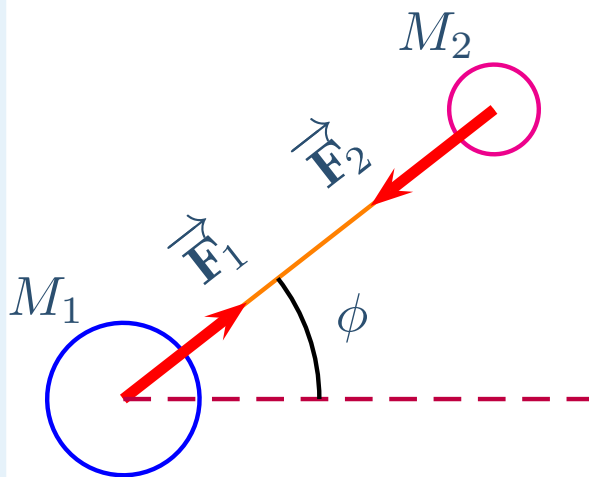
Geometry determines direction

f. b. d. for M_1



Direction

The gravitational force is an “attractive” force \Rightarrow each object feels a force towards the other.

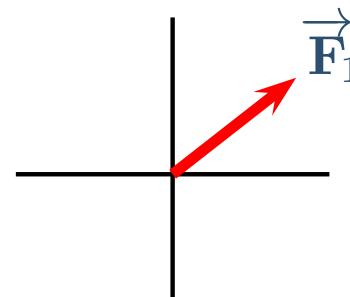


\vec{F}_1 - Force on 1 due to 2

\vec{F}_2 - Force on 2 due to 1

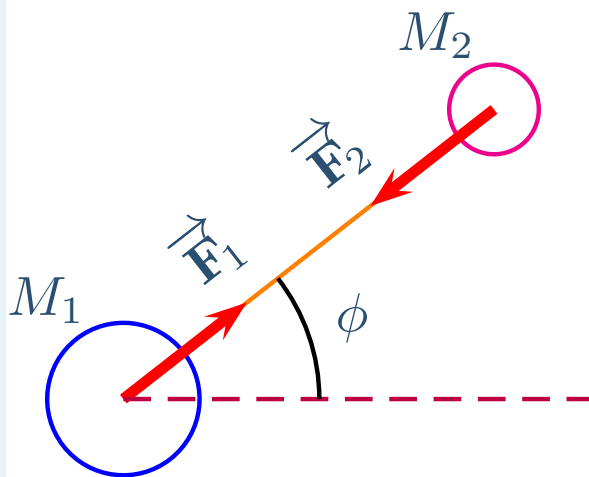
Geometry determines direction

f. b. d. for M_1



Direction

The gravitational force is an “attractive” force \Rightarrow each object feels a force towards the other.

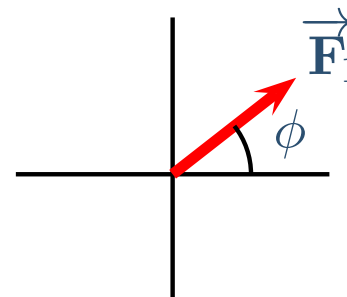


\vec{F}_1 - Force on 1 due to 2

\vec{F}_2 - Force on 2 due to 1

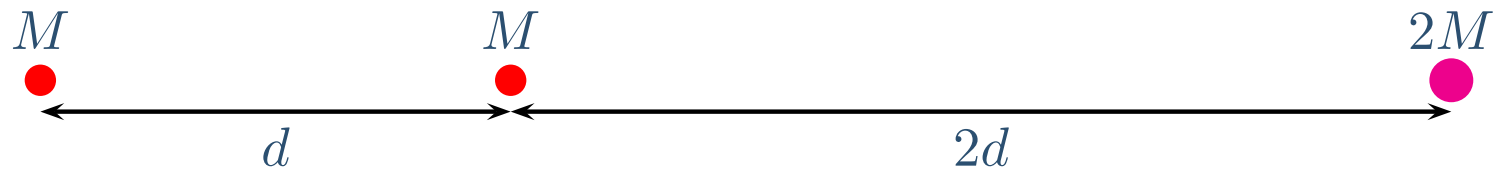
Geometry determines direction

f. b. d. for M_1



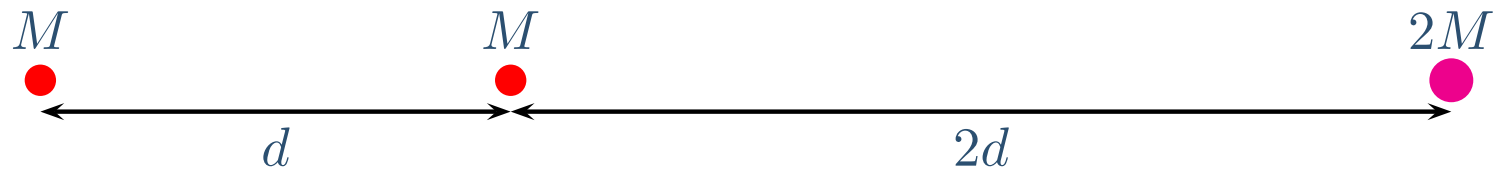
Direction Exercise

Three masses are arranged in a line with the distance between the second and third double that of the distance between the first and second. If the third mass is twice as large as the other two, what direction is the net gravitational force acting on the middle mass?



Direction Exercise

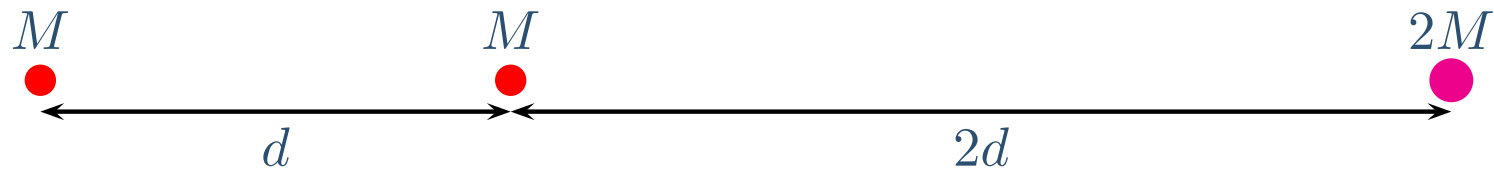
Three masses are arranged in a line with the distance between the second and third double that of the distance between the first and second. If the third mass is twice as large as the other two, what direction is the net gravitational force acting on the middle mass?



(a) Left

Direction Exercise

Three masses are arranged in a line with the distance between the second and third double that of the distance between the first and second. If the third mass is twice as large as the other two, what direction is the net gravitational force acting on the middle mass?

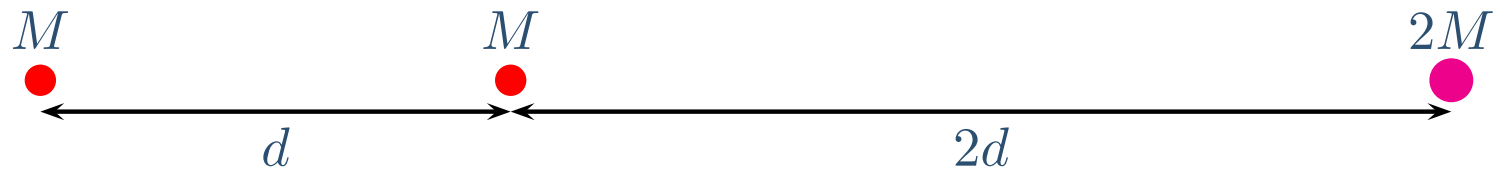


(a) Left

(b) Right

Direction Exercise

Three masses are arranged in a line with the distance between the second and third double that of the distance between the first and second. If the third mass is twice as large as the other two, what direction is the net gravitational force acting on the middle mass?



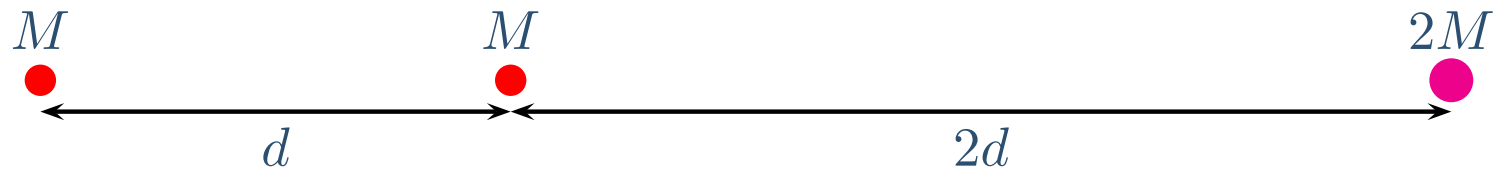
(a) Left

(b) Right

(c) Up

Direction Exercise

Three masses are arranged in a line with the distance between the second and third double that of the distance between the first and second. If the third mass is twice as large as the other two, what direction is the net gravitational force acting on the middle mass?



(a) Left

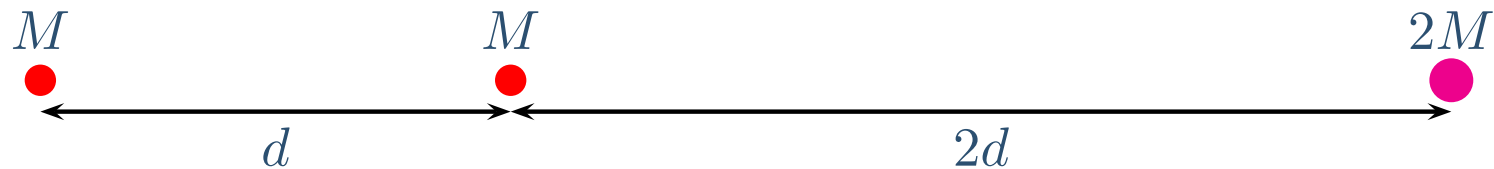
(b) Right

(c) Up

(d) Down

Direction Exercise

Three masses are arranged in a line with the distance between the second and third double that of the distance between the first and second. If the third mass is twice as large as the other two, what direction is the net gravitational force acting on the middle mass?



(a) Left

(b) Right

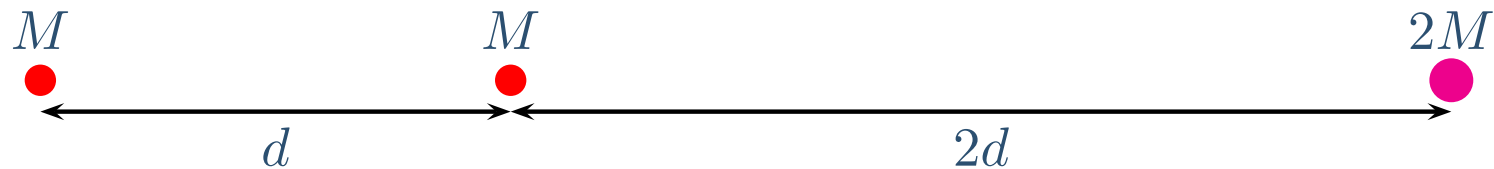
(c) Up

(d) Down

(e) The net force is zero

Direction Exercise

Three masses are arranged in a line with the distance between the second and third double that of the distance between the first and second. If the third mass is twice as large as the other two, what direction is the net gravitational force acting on the middle mass?



(a) Left

(b) Right

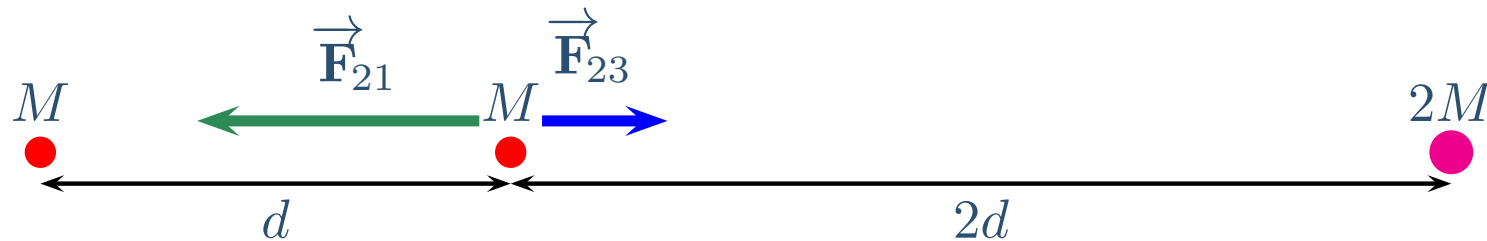
(c) Up

(d) Down

(e) The net force is zero

Direction Exercise

Three masses are arranged in a line with the distance between the second and third double that of the distance between the first and second. If the third mass is twice as large as the other two, what direction is the net gravitational force acting on the middle mass?



(a) Left

$$F_{21} = \frac{G(M)(M)}{d^2} = \frac{GM^2}{d^2}$$

$$F_{23} = \frac{G(M)(2m)}{(2d)^2} = \frac{2GM^2}{4d^2} = \frac{1}{2} \frac{GM^2}{d^2}$$

Weight

Weight - Force due to gravity.

Weight

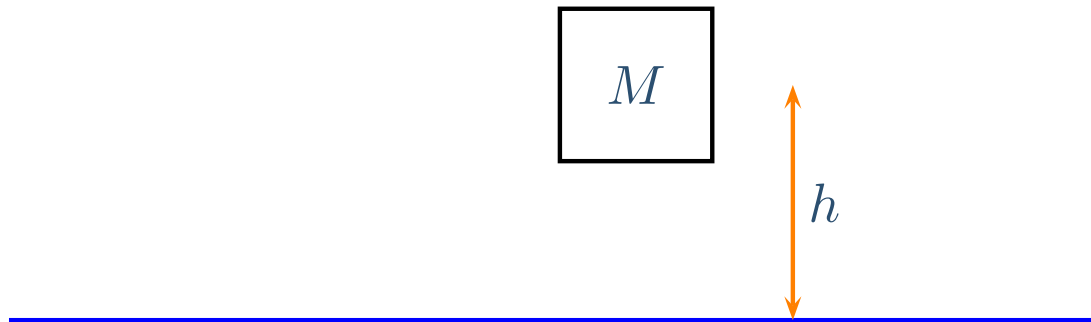
Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:

Weight

Weight - Force due to gravity.

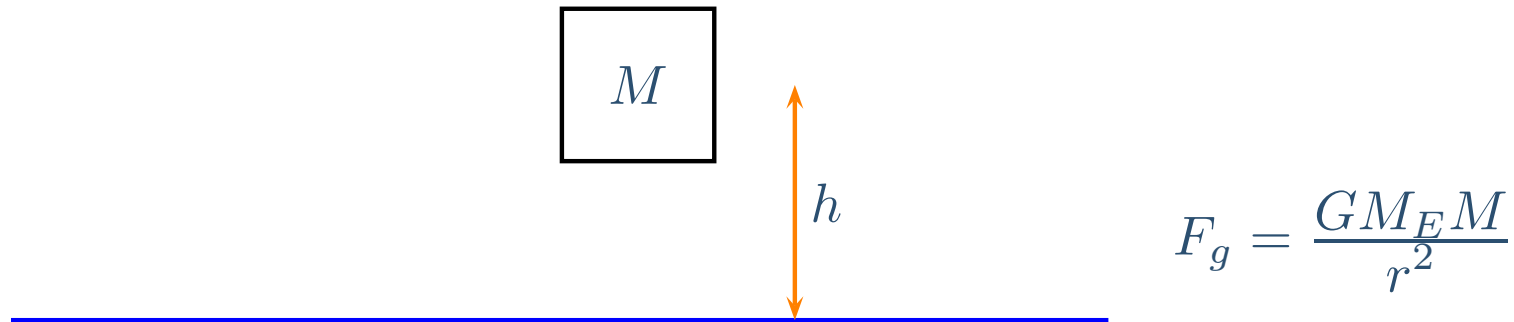
To relate what we used before (Mg) to Newton's law of gravity:



Weight

Weight - Force due to gravity.

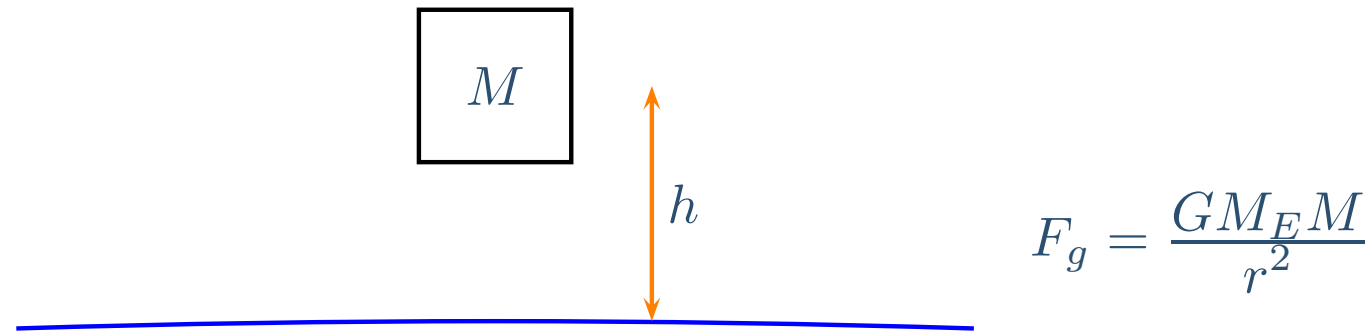
To relate what we used before (Mg) to Newton's law of gravity:



Weight

Weight - Force due to gravity.

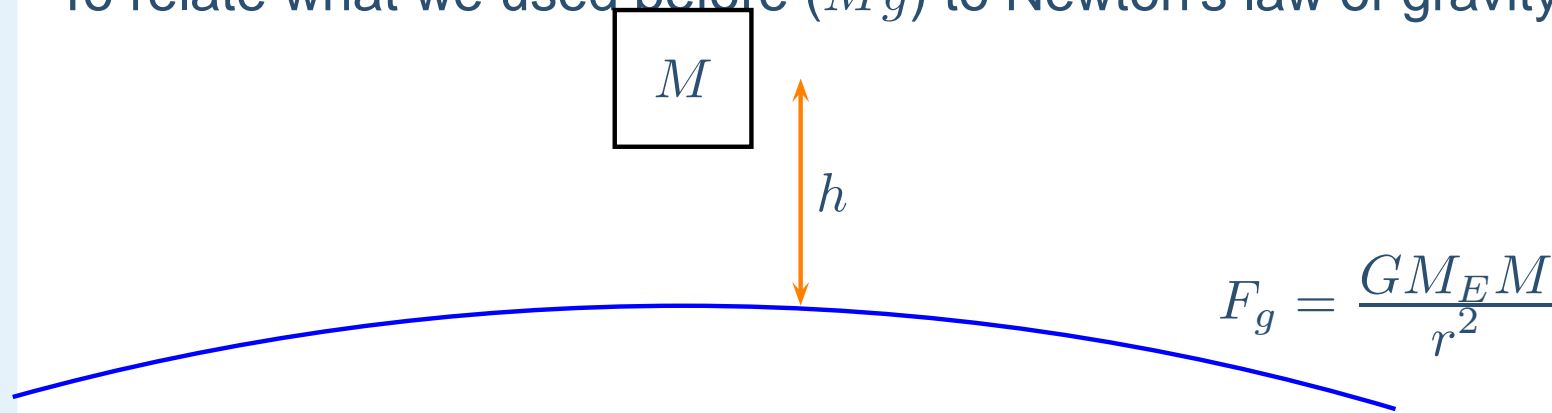
To relate what we used before (Mg) to Newton's law of gravity:



Weight

Weight - Force due to gravity.

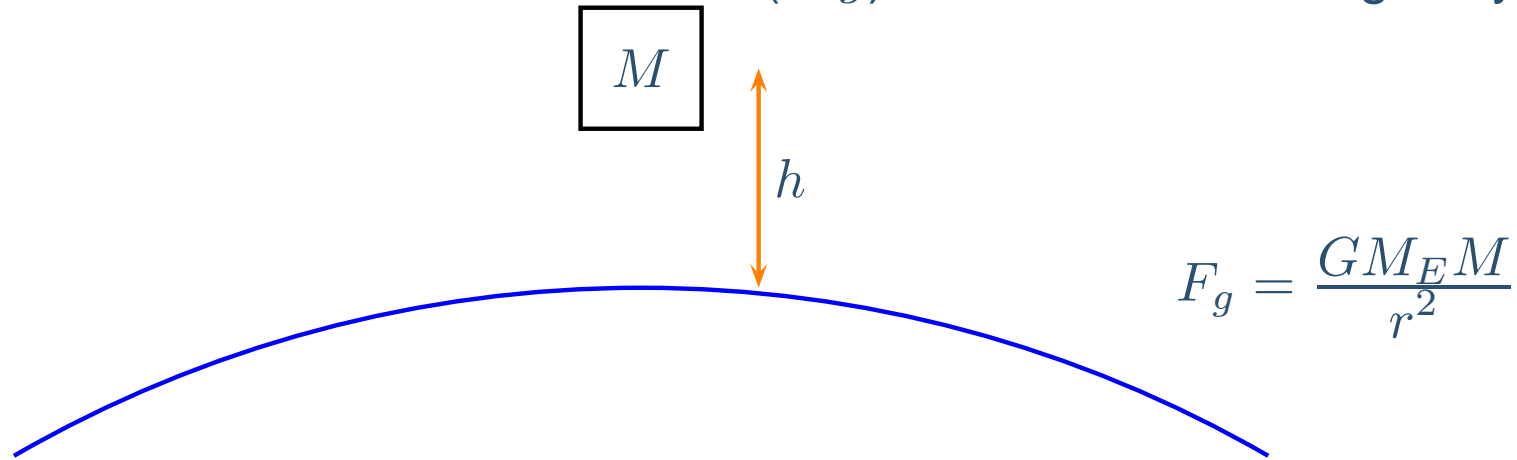
To relate what we used before (Mg) to Newton's law of gravity:



Weight

Weight - Force due to gravity.

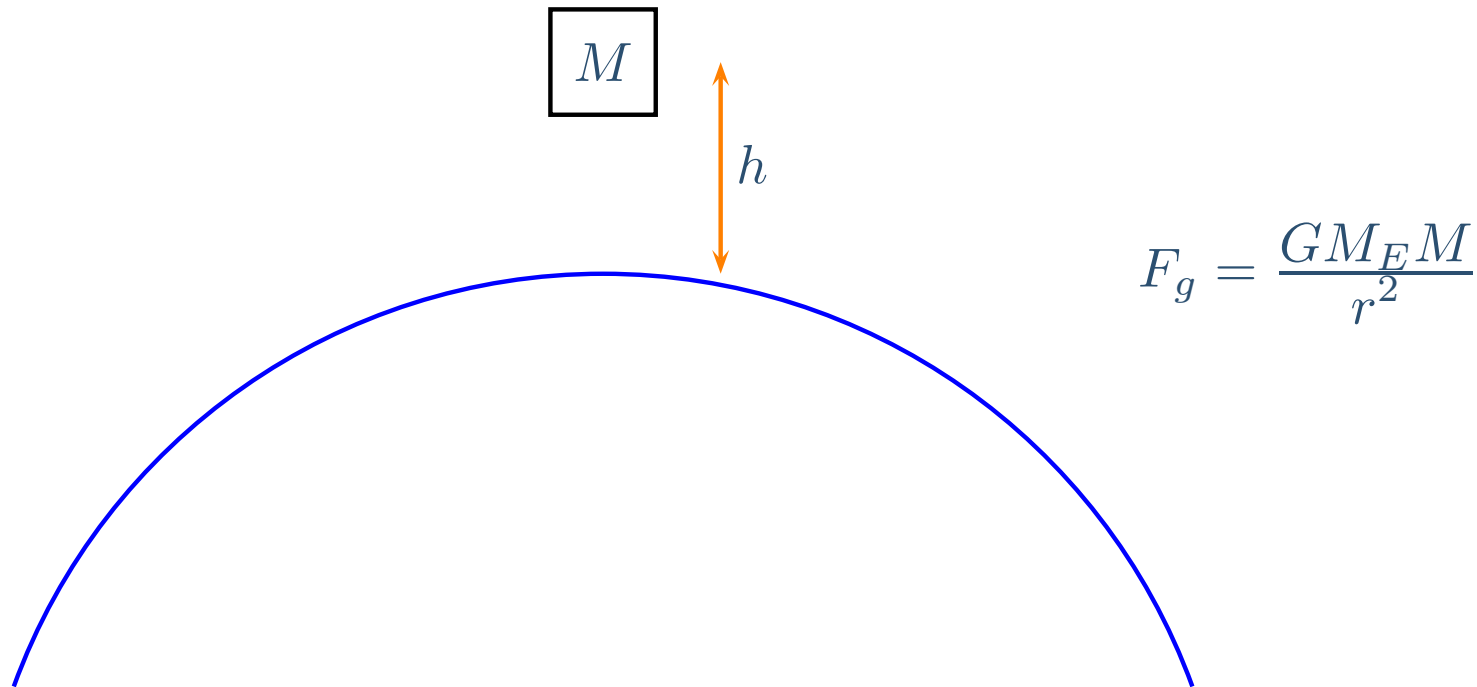
To relate what we used before (Mg) to Newton's law of gravity:



Weight

Weight - Force due to gravity.

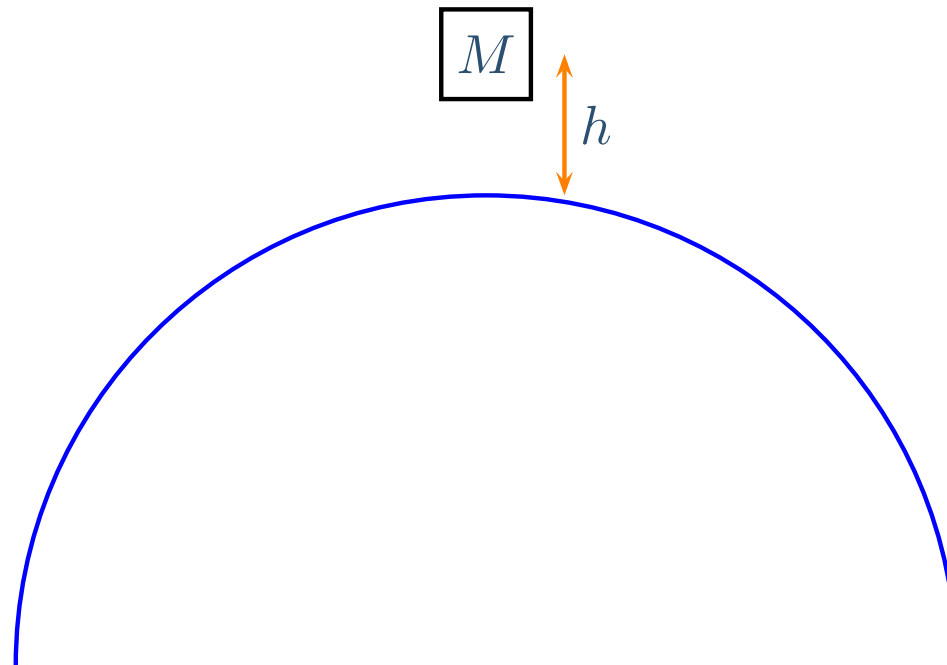
To relate what we used before (Mg) to Newton's law of gravity:



Weight

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:

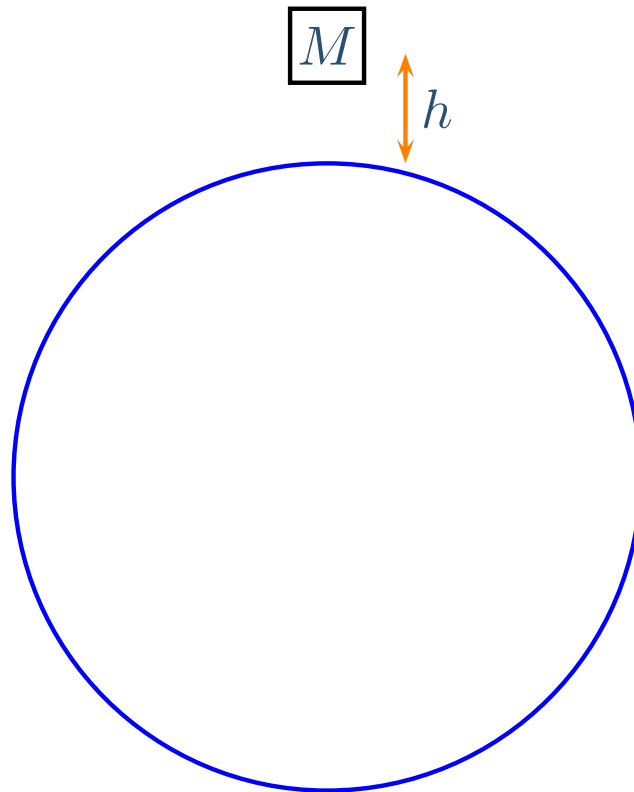


$$F_g = \frac{GM_E M}{r^2}$$

Weight

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:

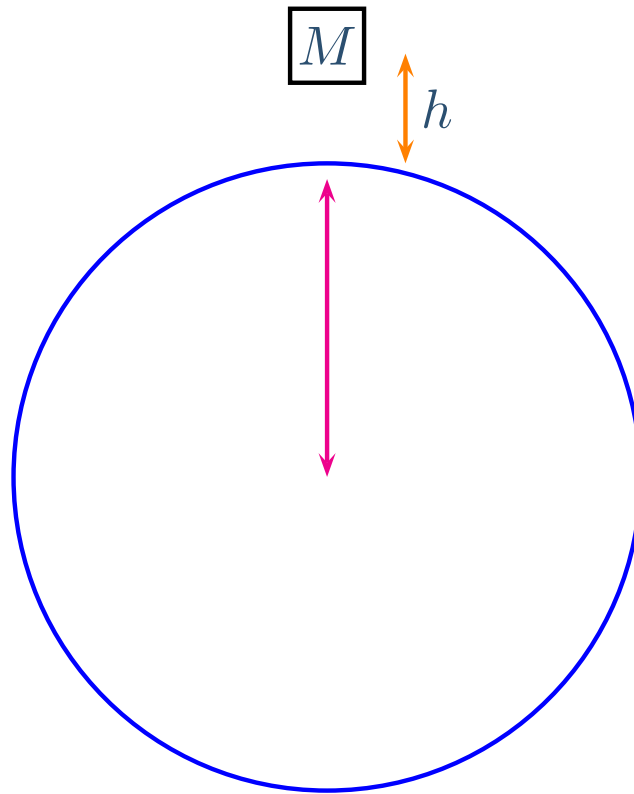


$$F_g = \frac{GM_E M}{r^2}$$

Weight

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:

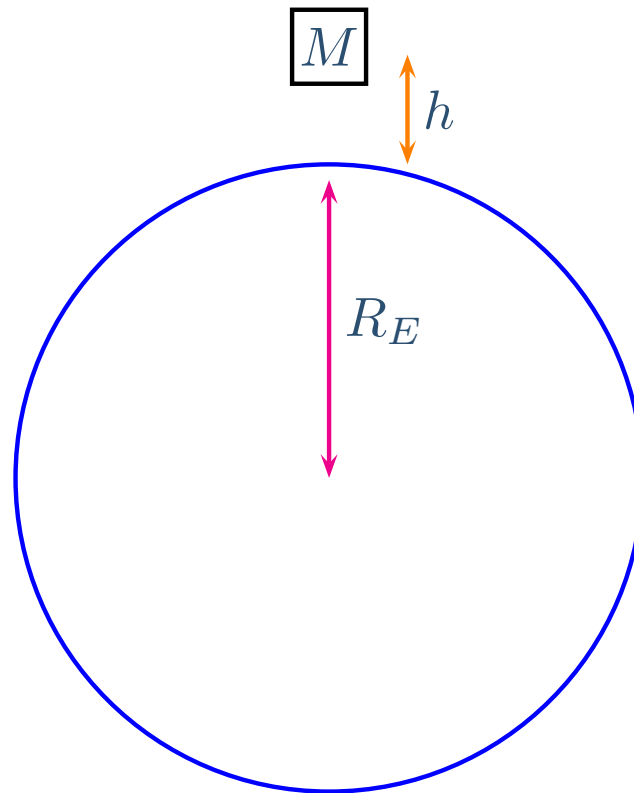


$$F_g = \frac{GM_E M}{r^2}$$

Weight

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:



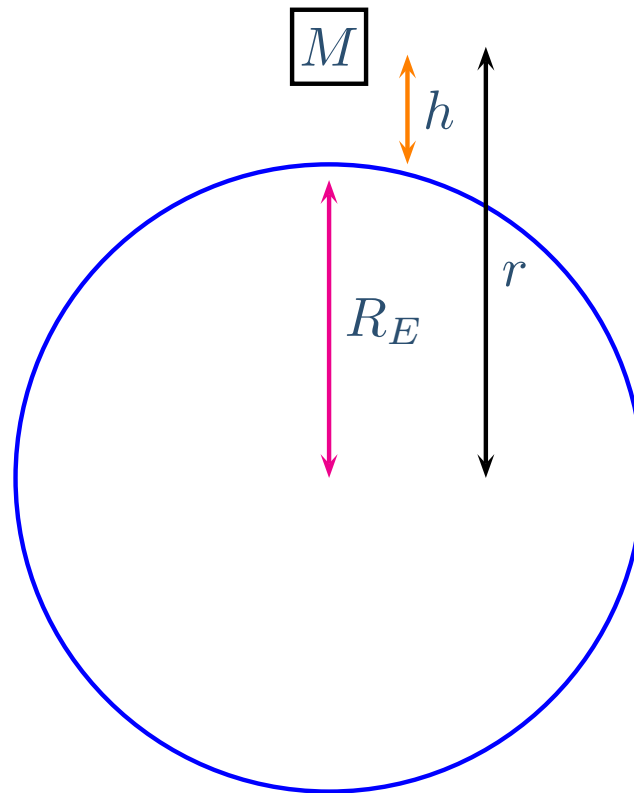
$$F_g = \frac{GM_E M}{r^2}$$

R_E - Earth's radius

Weight

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:



$$F_g = \frac{GM_E M}{r^2}$$

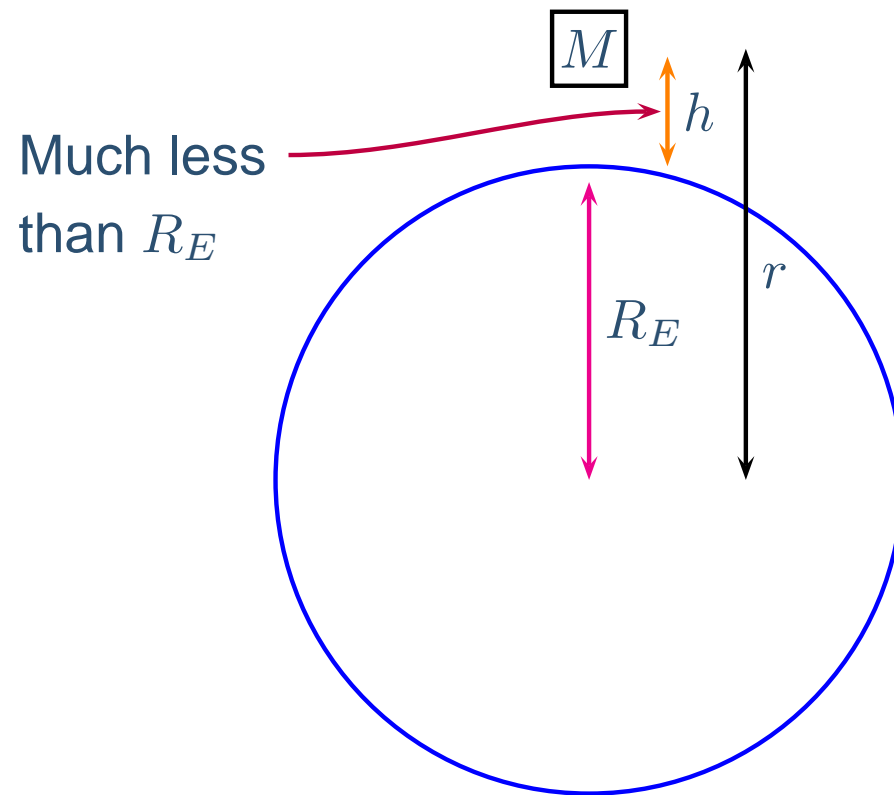
R_E - Earth's radius

$$r = R_E + h$$

Weight

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:



$$F_g = \frac{GM_E M}{r^2}$$

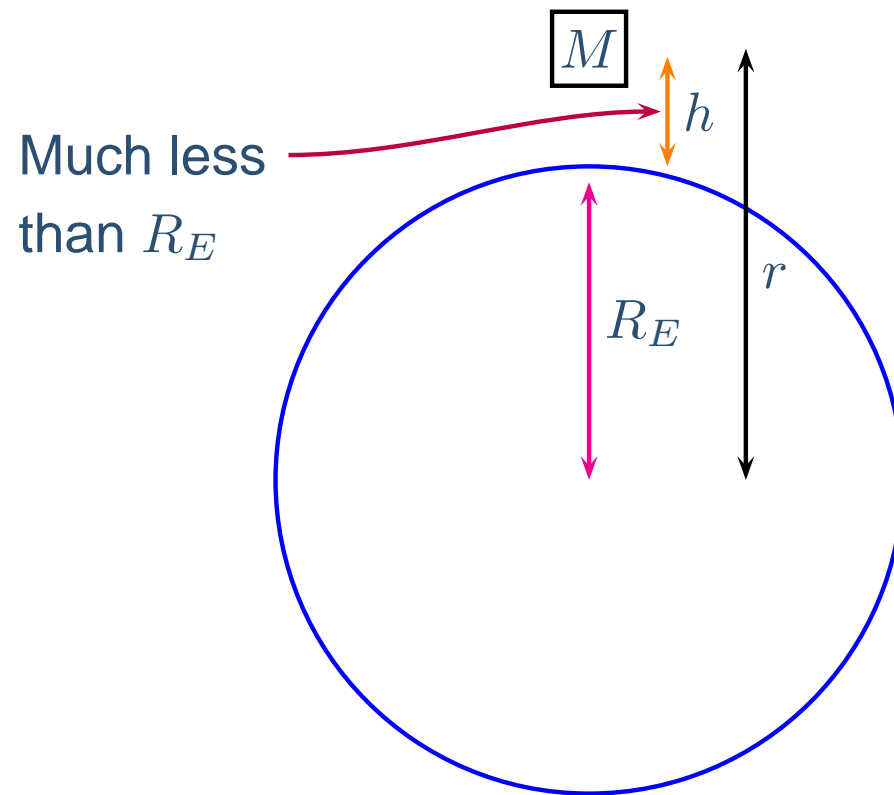
R_E - Earth's radius

$$r = R_E + h$$

Weight

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:



$$F_g = \frac{GM_E M}{r^2}$$

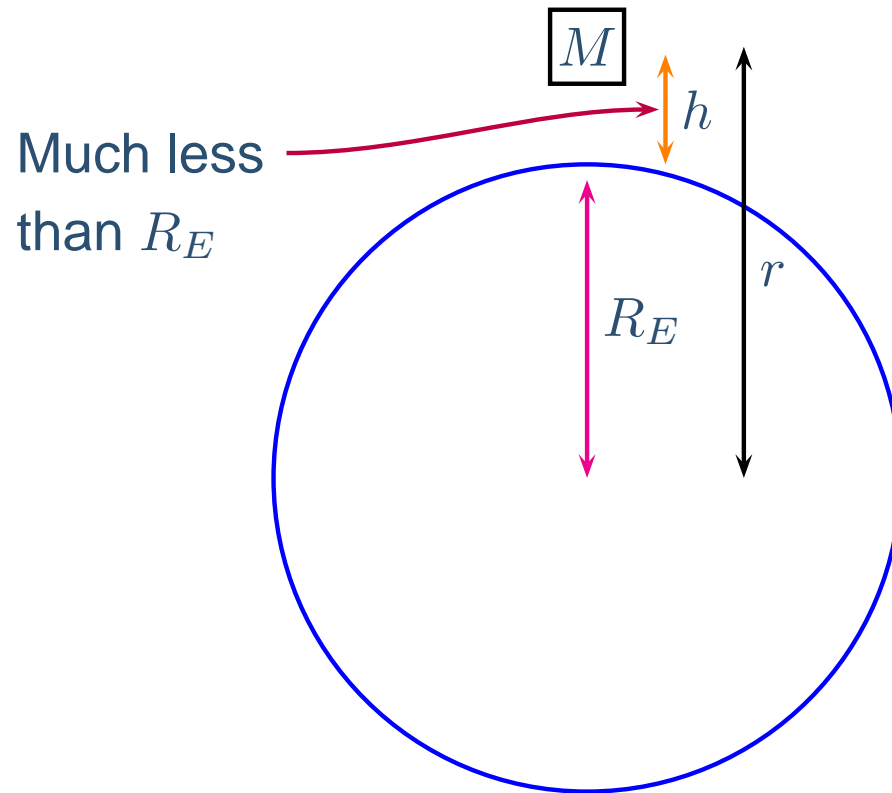
R_E - Earth's radius

$$r = R_E + h \approx R_E$$

Weight

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:



$$F_g = \frac{GM_E M}{r^2}$$

R_E - Earth's radius

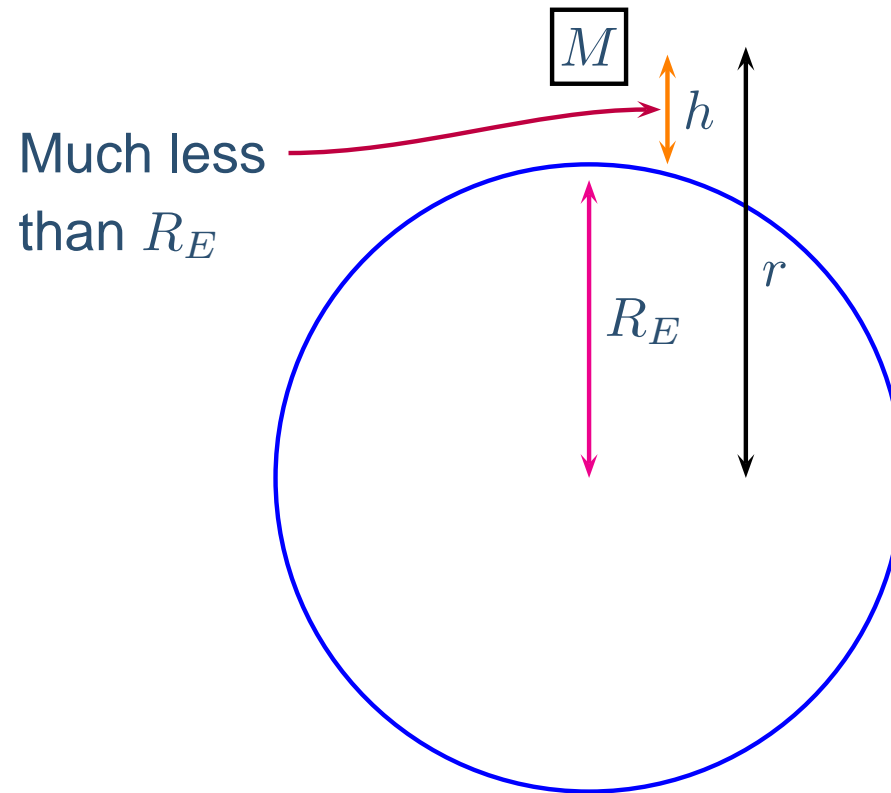
$$r = R_E + h \approx R_E$$

$$F_g = \frac{GM_E M}{R_E^2}$$

Weight

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:



$$F_g = \frac{GM_E M}{r^2}$$

R_E - Earth's radius

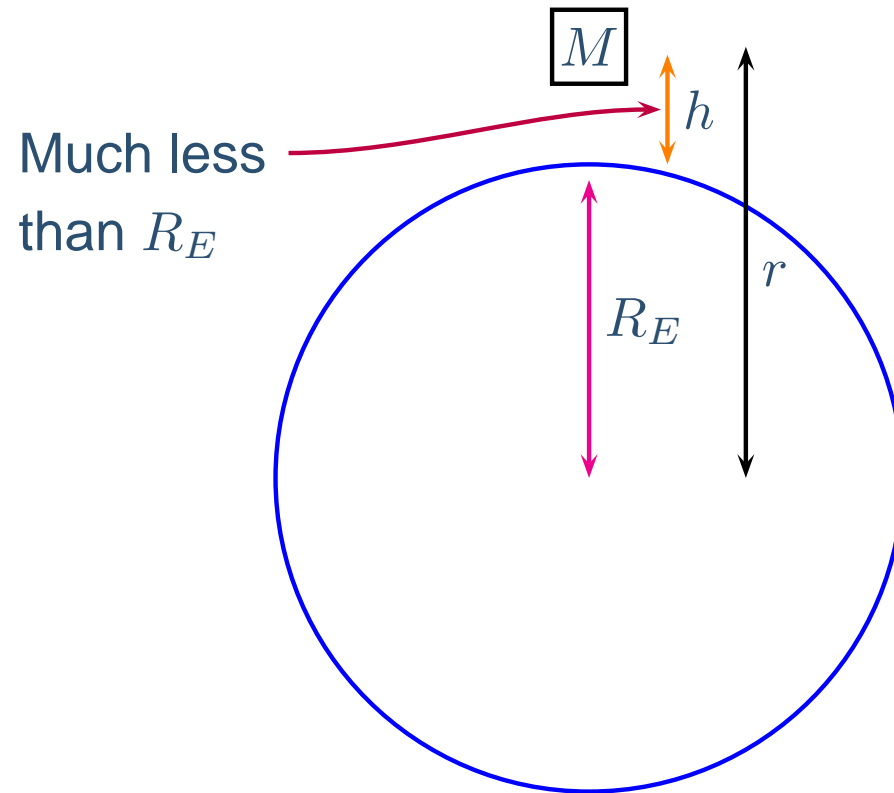
$$r = R_E + h \approx R_E$$

$$F_g = \frac{GM_E M}{R_E^2} = M \left(\frac{GM_E}{R_E^2} \right)$$

Acceleration due to gravity

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:

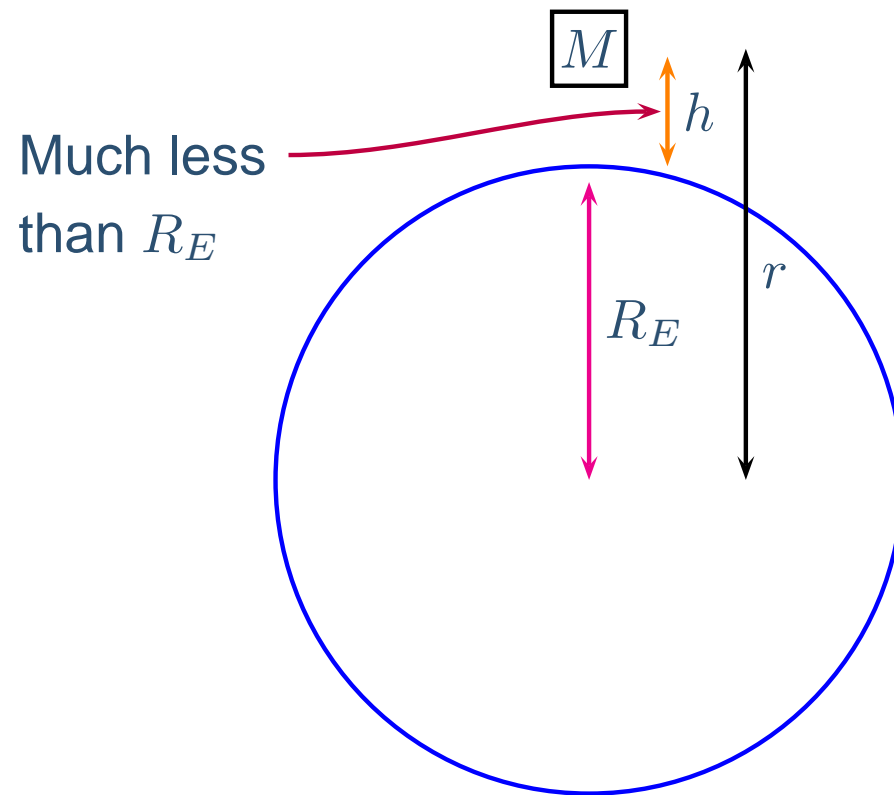


$$F_g = M \left(\frac{GM_E}{R_E^2} \right)$$

Acceleration due to gravity

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:

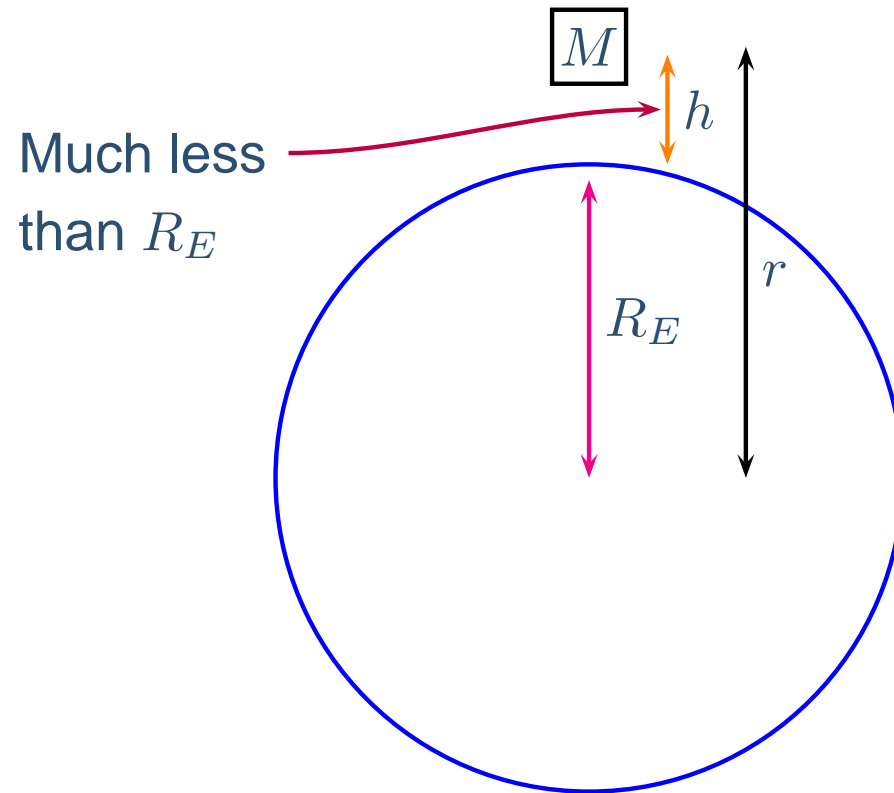


$$F_g = M \left(\frac{GM_E}{R_E^2} \right) = Mg$$

Acceleration due to gravity

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:



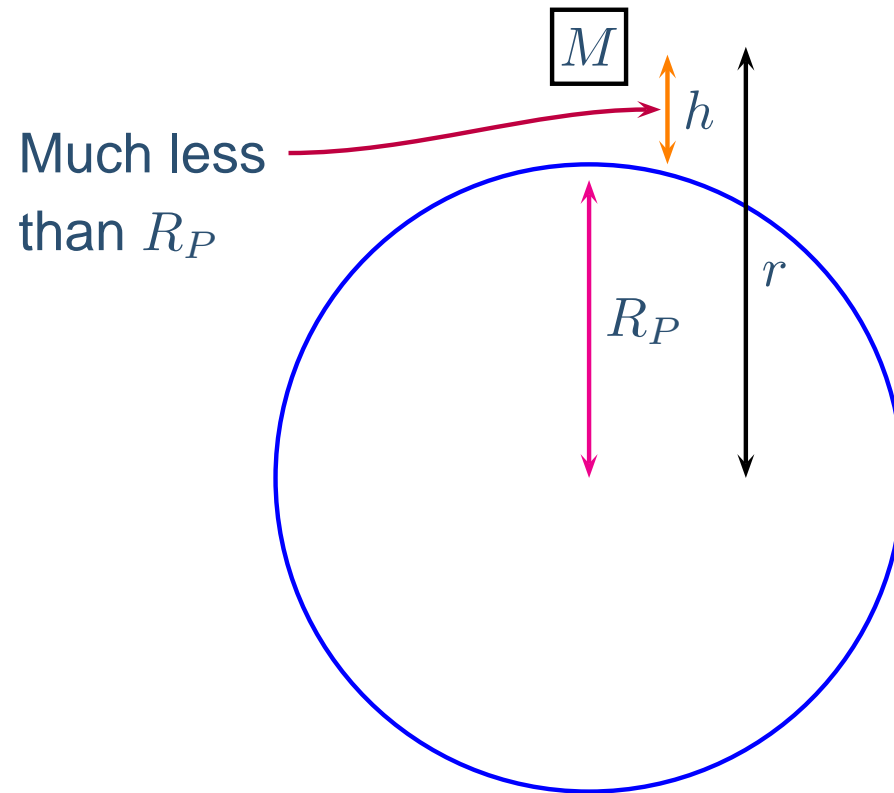
$$F_g = M \left(\frac{GM_E}{R_E^2} \right) = Mg$$

$$\left(\frac{GM_E}{R_E^2} \right) = 9.782 \text{ m/s}^2$$

Acceleration due to gravity

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:



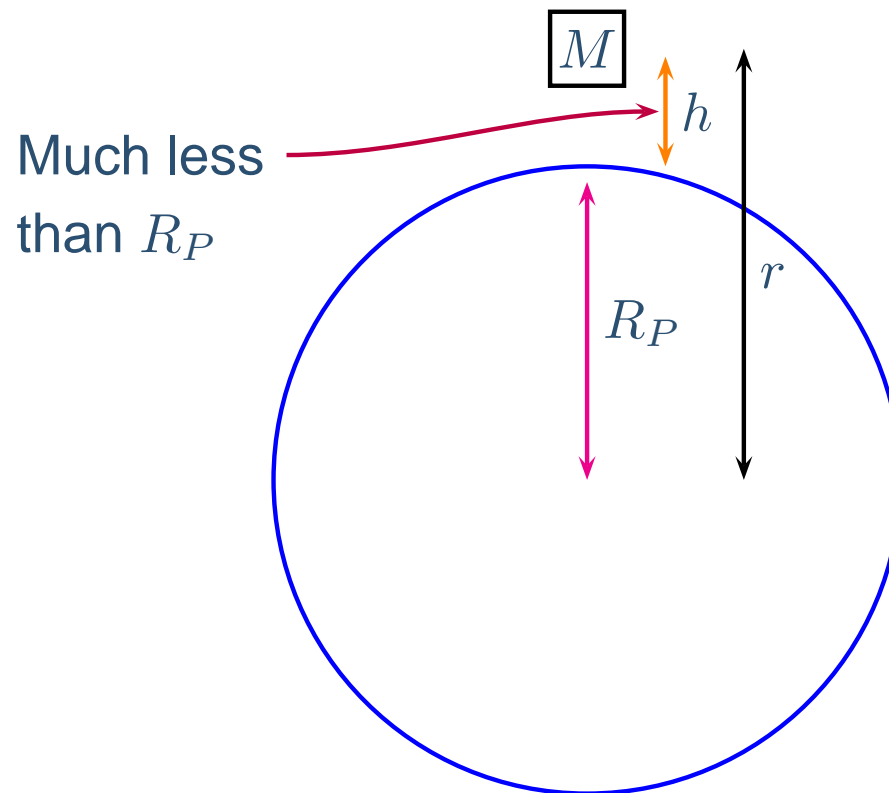
$$F_g = M \left(\frac{GM_E}{R_E^2} \right) = Mg$$

$$\left(\frac{GM_E}{R_E^2} \right) = 9.782 \text{ m/s}^2$$

Acceleration due to gravity

Weight - Force due to gravity.

To relate what we used before (Mg) to Newton's law of gravity:



$$F_g = M \left(\frac{GM_E}{R_E^2} \right) = Mg$$

$$\left(\frac{GM_E}{R_E^2} \right) = 9.782 \text{ m/s}^2$$

Acceleration due to gravity

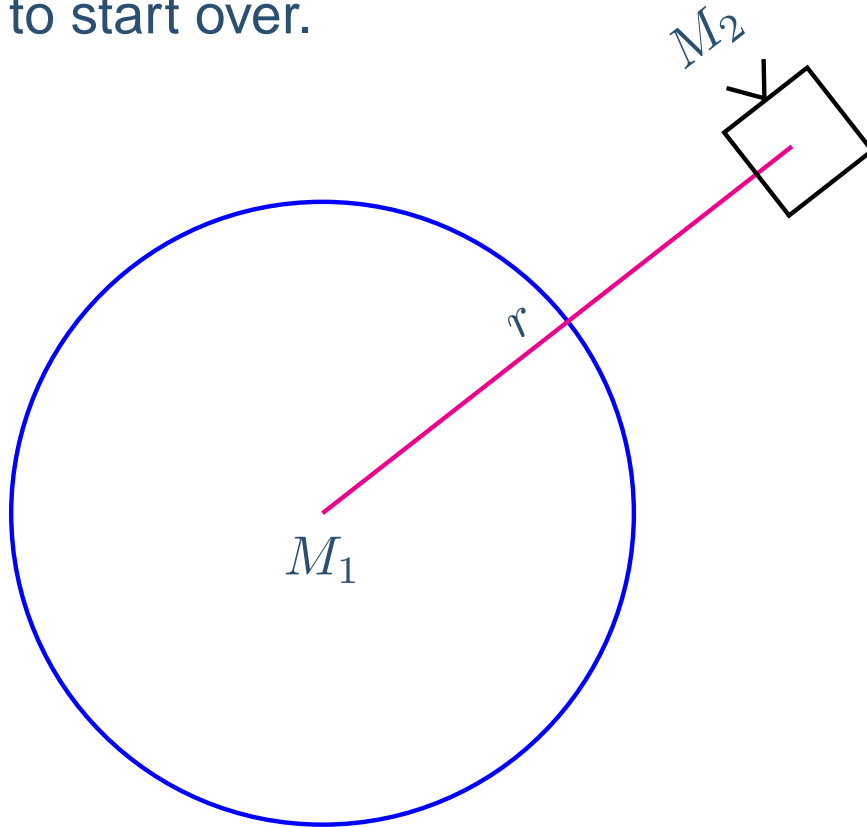
on any planet: $g = \frac{GM_P}{R_P^2}$

Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.

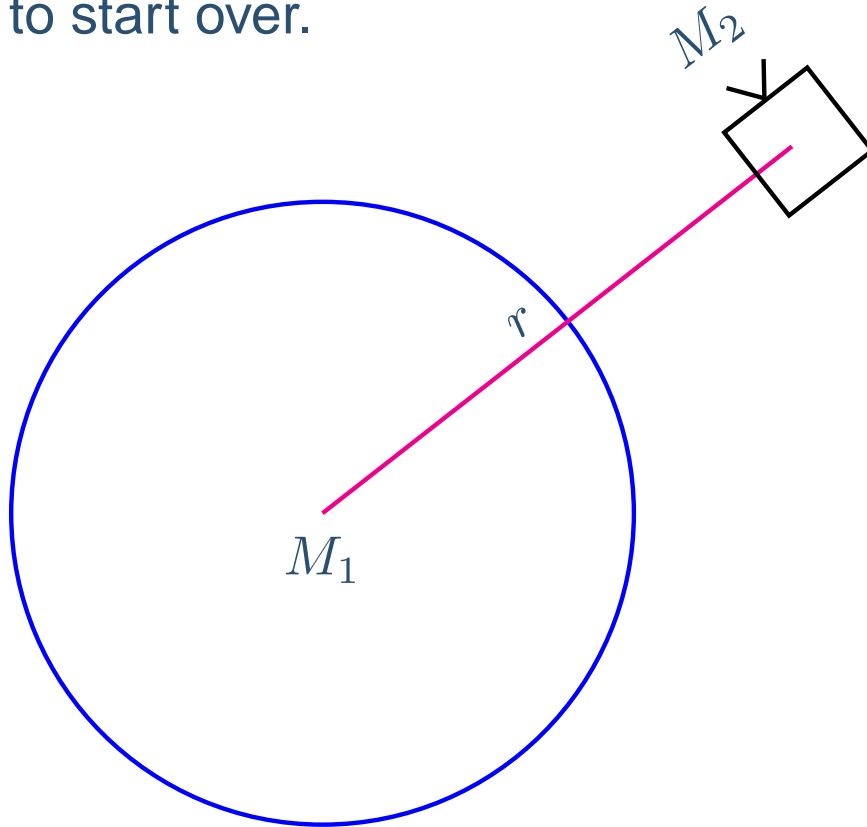
Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.



Gravitational Potential Energy

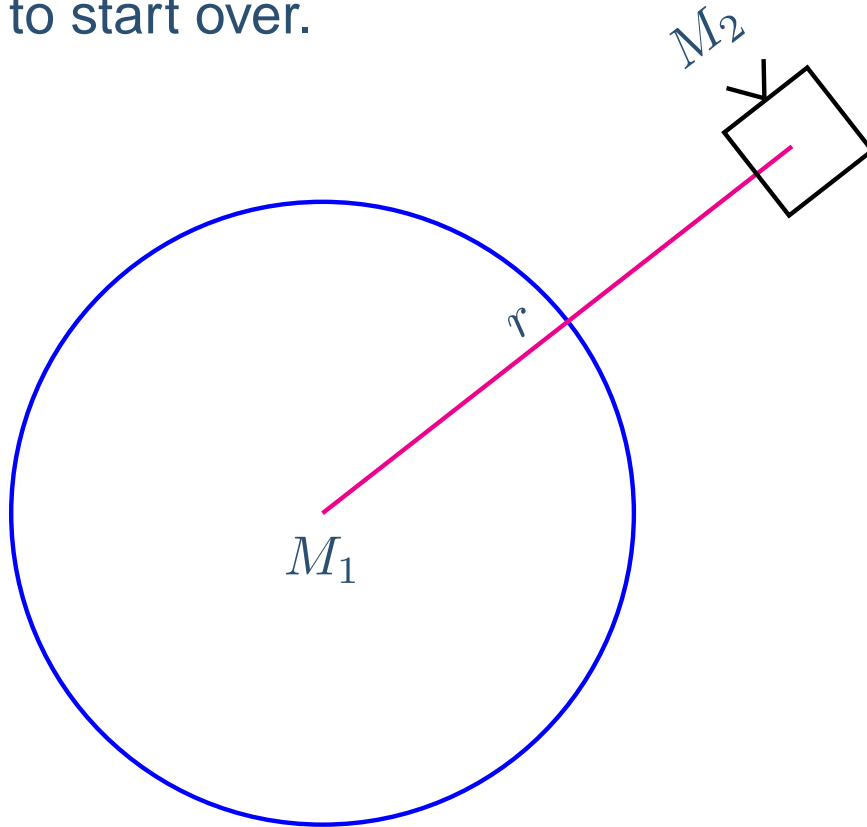
Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.



$$W_g = -\Delta U_g = -U_2 + U_1$$

Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.

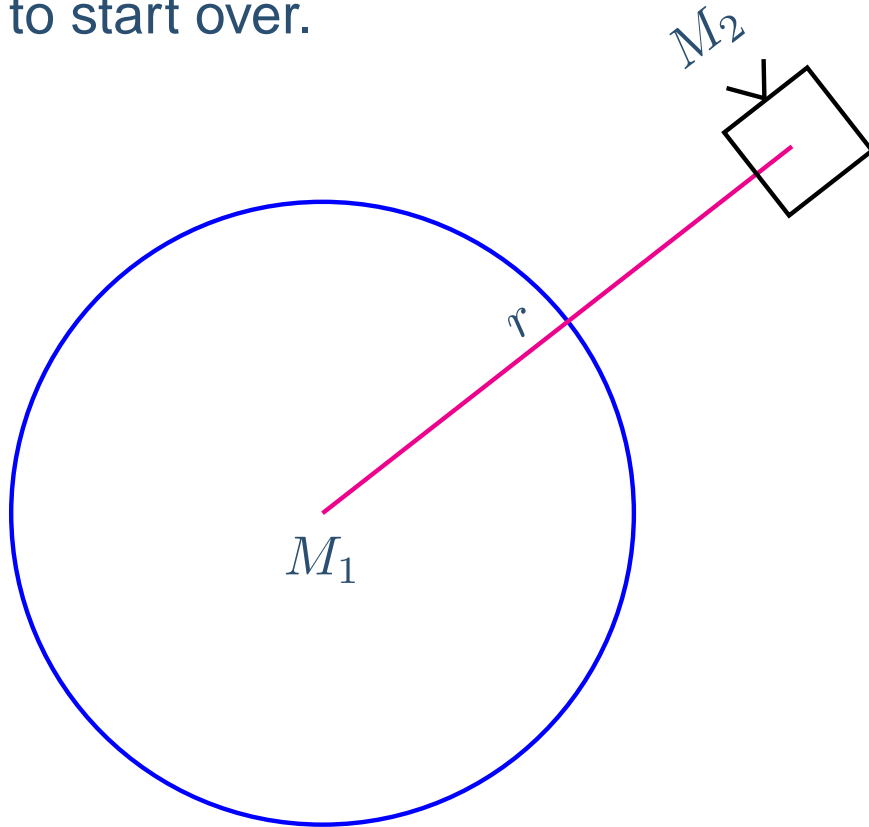


$$W_g = -\Delta U_g = -U_2 + U_1$$

Force not constant \Rightarrow integration

Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.



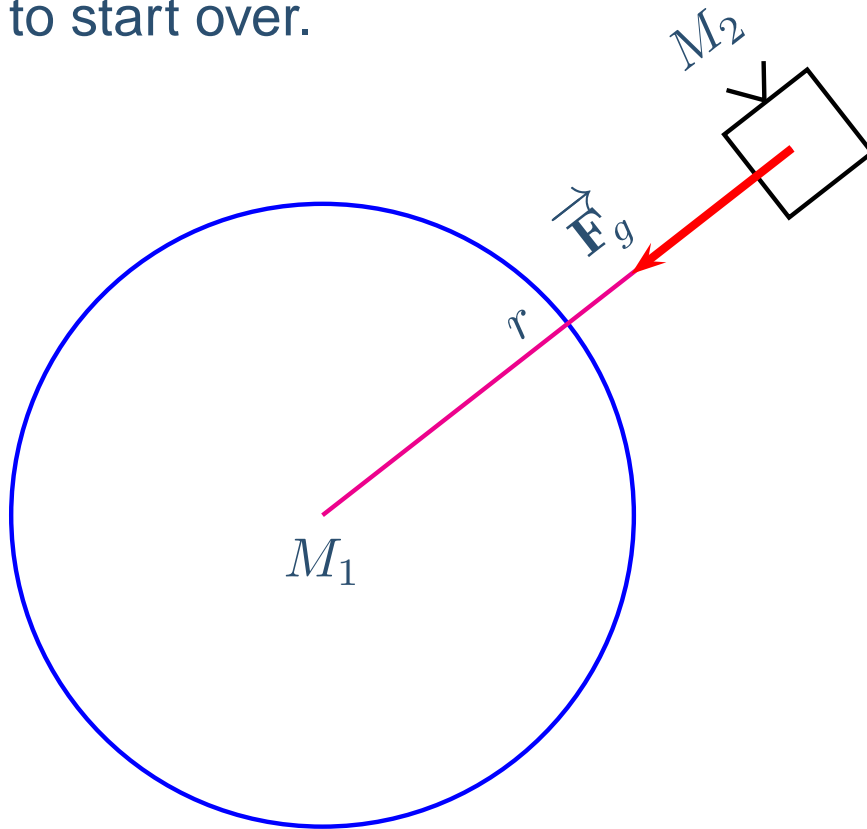
$$W_g = -\Delta U_g = -U_2 + U_1$$

Force not constant \Rightarrow integration

$$W_g = \int_{r_1}^{r_2} \vec{\mathbf{F}}_g \cdot d\vec{\mathbf{r}}$$

Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.



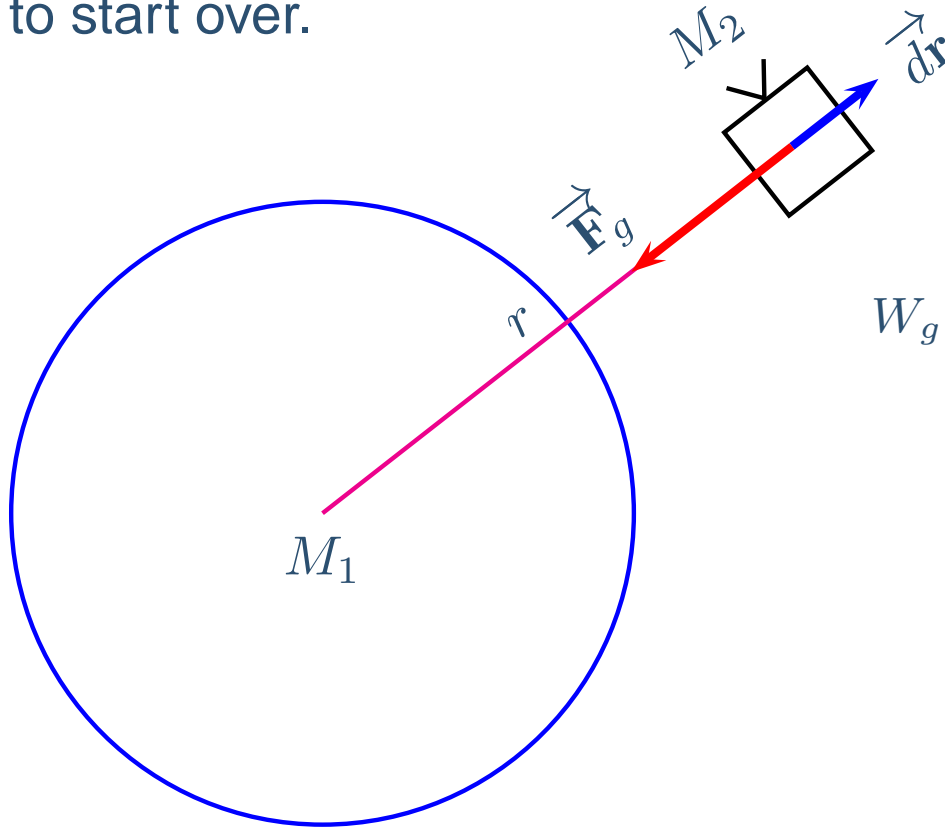
$$W_g = -\Delta U_g = -U_2 + U_1$$

Force not constant \Rightarrow integration

$$W_g = \int_{r_1}^{r_2} \vec{F}_g \cdot d\vec{r}$$

Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.



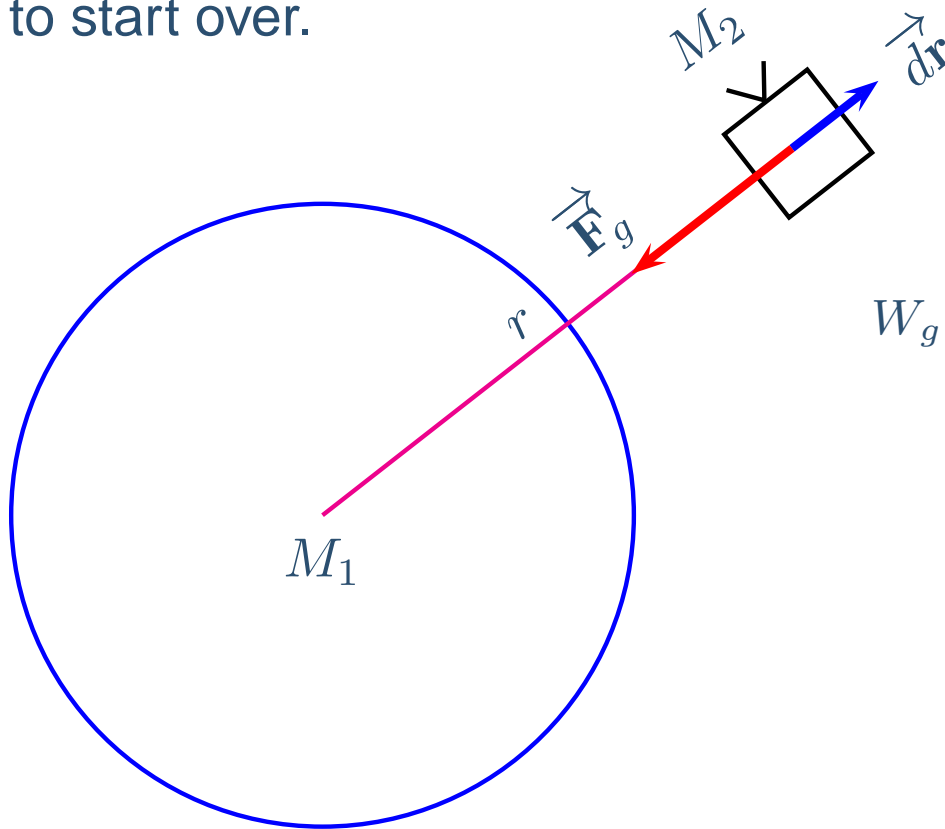
$$W_g = -\Delta U_g = -U_2 + U_1$$

Force not constant \Rightarrow integration

$$W_g = \int_{r_1}^{r_2} \vec{F}_g \cdot \vec{dr}$$

Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.



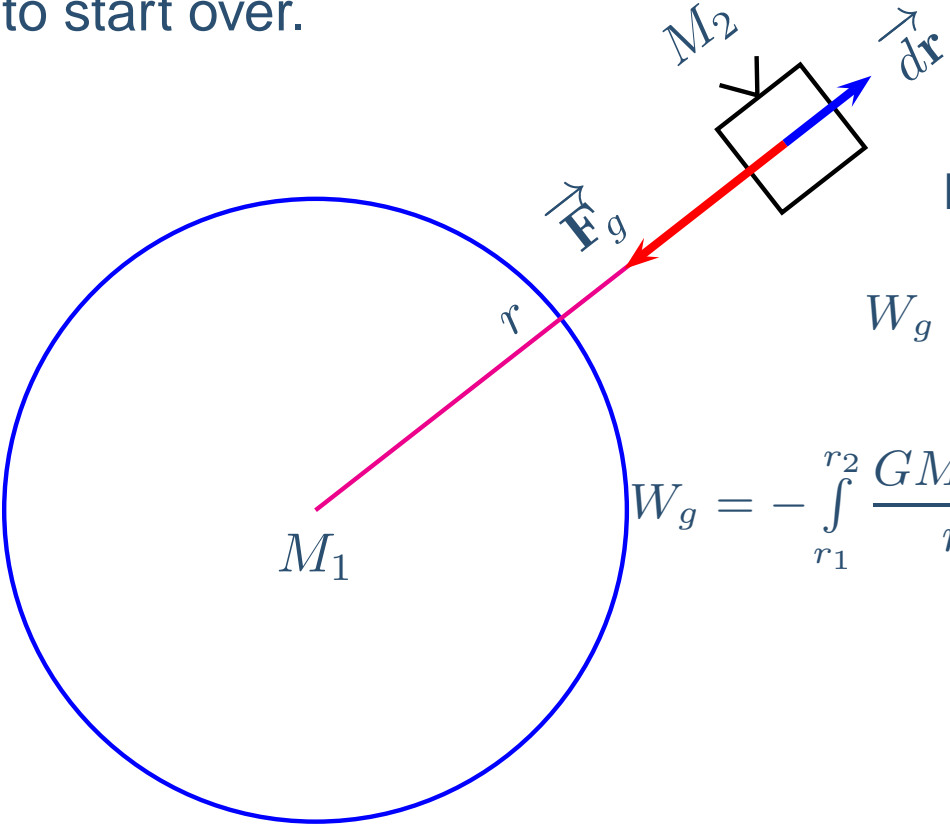
$$W_g = -\Delta U_g = -U_2 + U_1$$

Force not constant \Rightarrow integration

$$W_g = \int_{r_1}^{r_2} \vec{F}_g \cdot \vec{dr} = \int_{r_1}^{r_2} F_g dr \cos 180^\circ$$

Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.



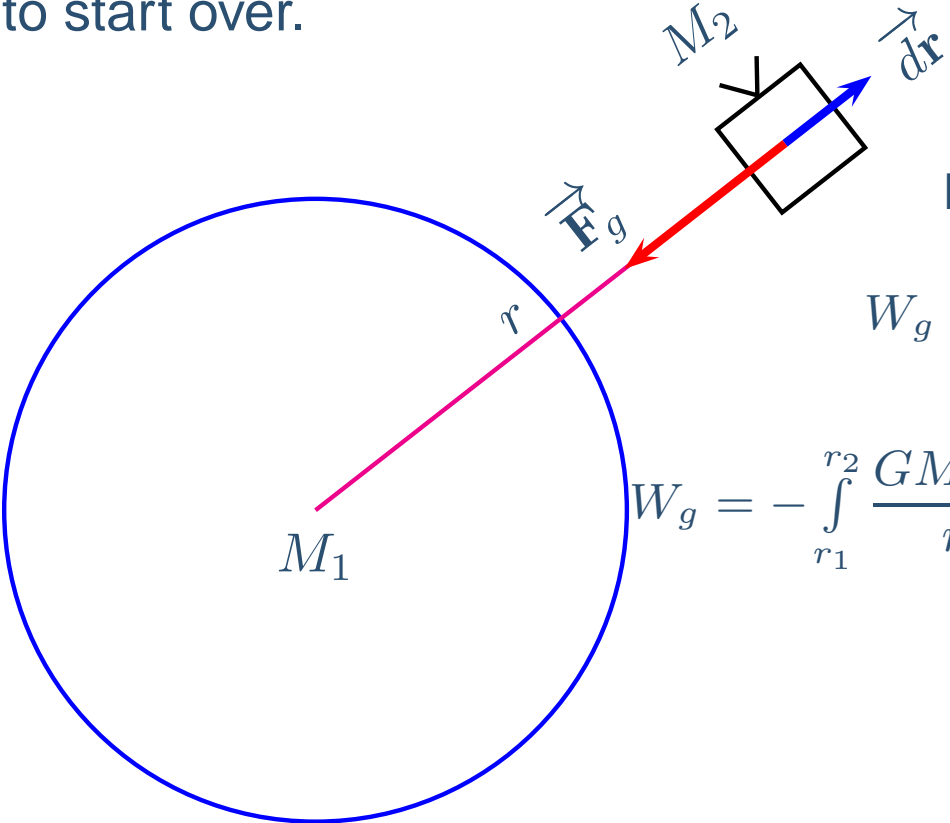
$W_g = -\Delta U_g = -U_2 + U_1$

Force not constant \Rightarrow integration

$$W_g = \int_{r_1}^{r_2} \vec{\mathbf{F}}_g \cdot \vec{dr} = \int_{r_1}^{r_2} F_g dr \cos 180^\circ$$
$$W_g = - \int_{r_1}^{r_2} \frac{GM_1 M_2}{r^2} dr$$

Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.



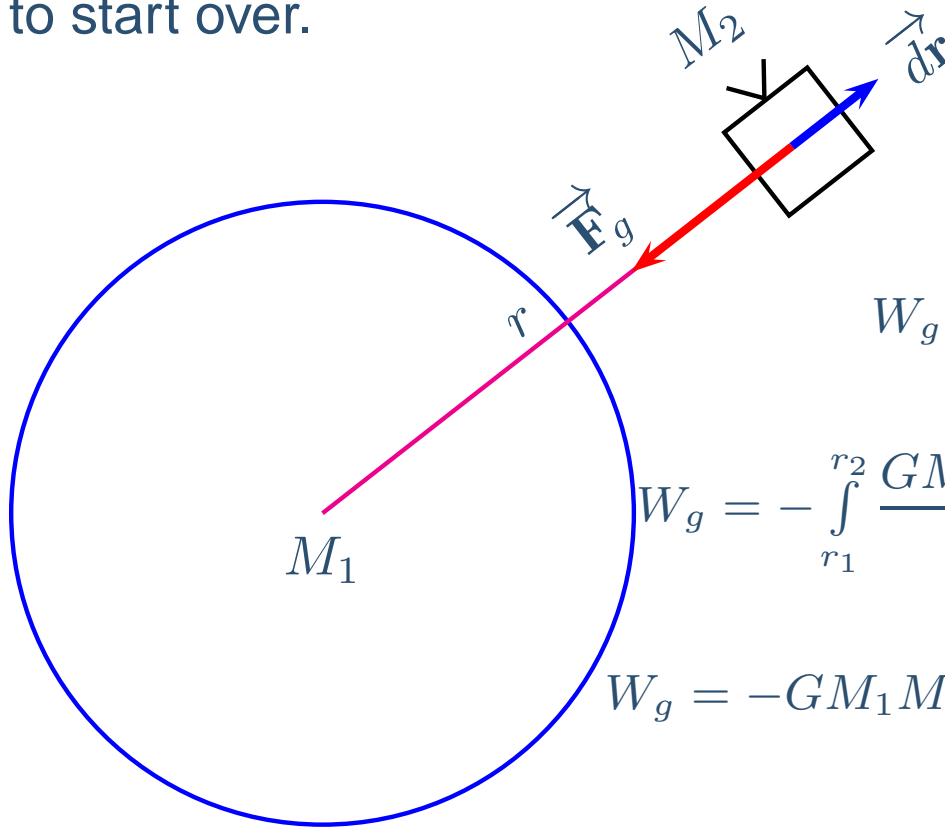
$W_g = -\Delta U_g = -U_2 + U_1$

Force not constant \Rightarrow integration

$$W_g = \int_{r_1}^{r_2} \vec{\mathbf{F}}_g \cdot \vec{dr} = \int_{r_1}^{r_2} F_g dr \cos 180^\circ$$
$$W_g = - \int_{r_1}^{r_2} \frac{GM_1 M_2}{r^2} dr = -GM_1 M_2 \int_{r_1}^{r_2} \frac{1}{r^2} dr$$

Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.



$$W_g = -\Delta U_g = -U_2 + U_1$$

Force not constant \Rightarrow integration

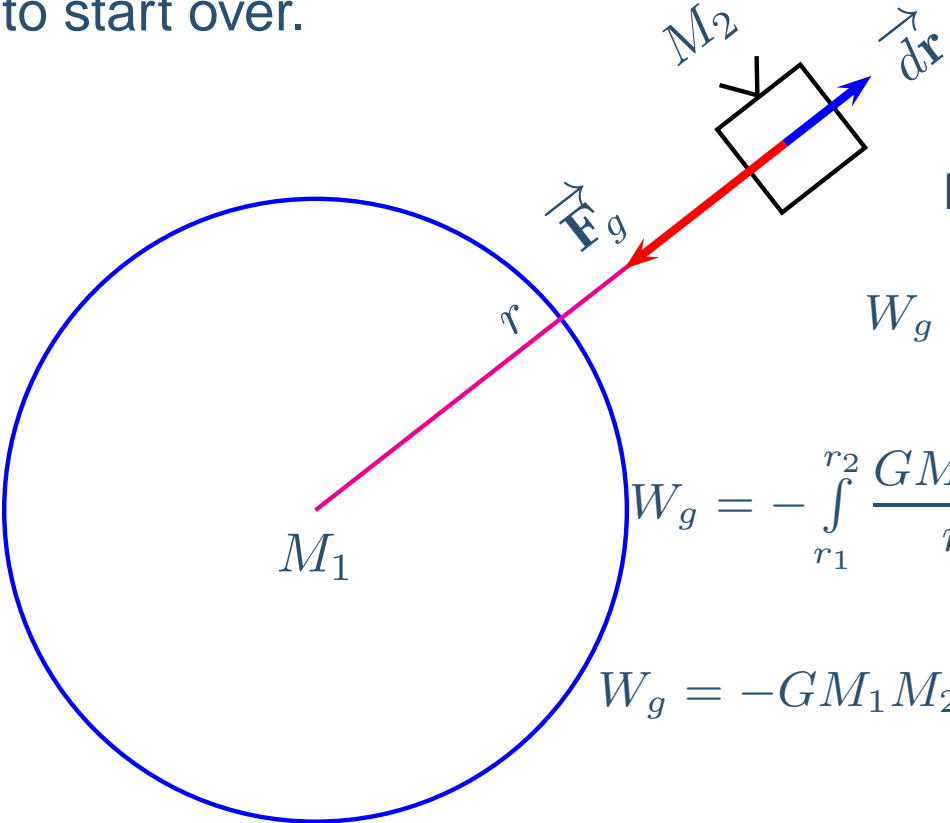
$$W_g = \int_{r_1}^{r_2} \vec{F}_g \cdot \vec{dr} = \int_{r_1}^{r_2} F_g dr \cos 180^\circ$$

$$W_g = - \int_{r_1}^{r_2} \frac{GM_1 M_2}{r^2} dr = -GM_1 M_2 \int_{r_1}^{r_2} \frac{1}{r^2} dr$$

$$W_g = -GM_1 M_2 \left(-\frac{1}{r} \right) \Big|_{r_1}^{r_2}$$

Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.



$W_g = -\Delta U_g = -U_2 + U_1$
 Force not constant \Rightarrow integration
 $W_g = \int_{r_1}^{r_2} \vec{\mathbf{F}}_g \cdot \vec{dr} = \int_{r_1}^{r_2} F_g dr \cos 180^\circ$
 $W_g = - \int_{r_1}^{r_2} \frac{GM_1 M_2}{r^2} dr = -GM_1 M_2 \int_{r_1}^{r_2} \frac{1}{r^2} dr$
 $W_g = -GM_1 M_2 \left(-\frac{1}{r}\right) \Big|_{r_1}^{r_2} = \frac{GM_1 M_2}{r_2} - \frac{GM_1 M_2}{r_1}$

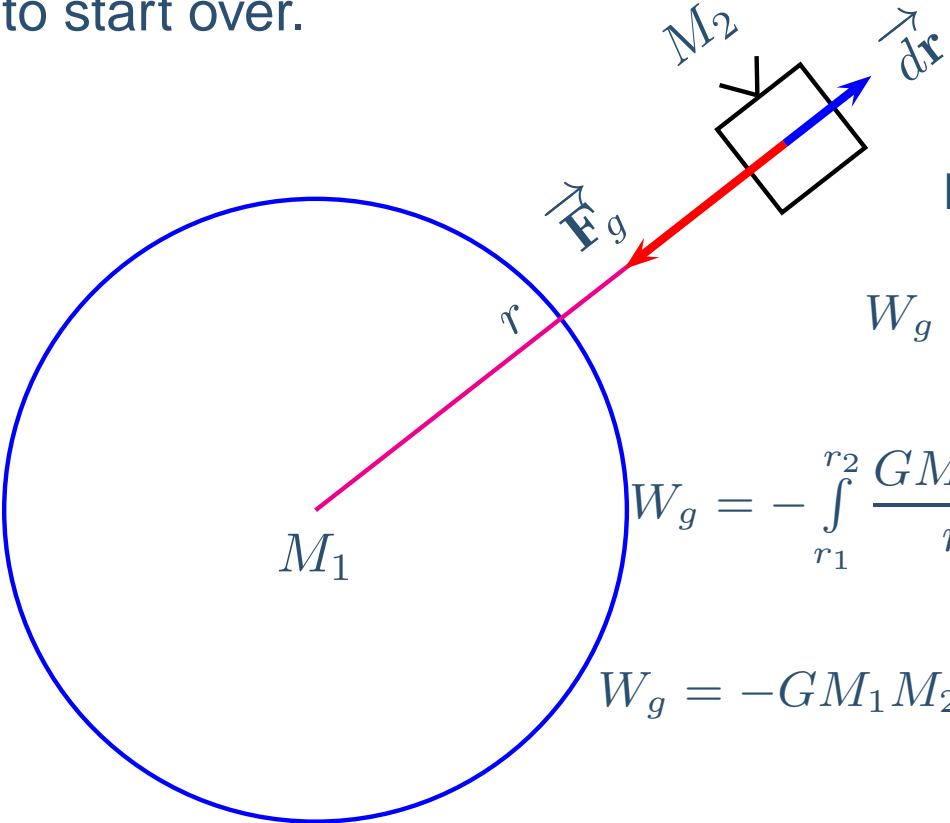
Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.

$W_g = -\Delta U_g = -U_2 + U_1$
 Force not constant \Rightarrow integration
 $W_g = \int_{r_1}^{r_2} \vec{\mathbf{F}}_g \cdot \vec{dr} = \int_{r_1}^{r_2} F_g dr \cos 180^\circ$
 $W_g = - \int_{r_1}^{r_2} \frac{GM_1 M_2}{r^2} dr = -GM_1 M_2 \int_{r_1}^{r_2} \frac{1}{r^2} dr$
 $W_g = -GM_1 M_2 \left(-\frac{1}{r}\right) \Big|_{r_1}^{r_2} = \frac{GM_1 M_2}{r_2} - \frac{GM_1 M_2}{r_1}$

Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.



$W_g = -\Delta U_g = -U_2 + U_1$
 Force not constant \Rightarrow integration
 $W_g = \int_{r_1}^{r_2} \vec{\mathbf{F}}_g \cdot \vec{dr} = \int_{r_1}^{r_2} F_g dr \cos 180^\circ$
 $W_g = - \int_{r_1}^{r_2} \frac{GM_1 M_2}{r^2} dr = -GM_1 M_2 \int_{r_1}^{r_2} \frac{1}{r^2} dr$
 $W_g = -GM_1 M_2 \left(-\frac{1}{r}\right) \Big|_{r_1}^{r_2} = \frac{GM_1 M_2}{r_2} - \frac{GM_1 M_2}{r_1}$

Gravitational Potential Energy

Our previous equation, $U_g = Mgy$, is valid for distance $y \ll R_P$. For distances large compared to the radius, we have to start over.

$$W_g = -\Delta U_g = -U_2 + U_1$$
 Force not constant \Rightarrow integration

$$W_g = \int_{r_1}^{r_2} \vec{\mathbf{F}}_g \cdot \vec{dr} = \int_{r_1}^{r_2} F_g dr \cos 180^\circ$$

$$W_g = - \int_{r_1}^{r_2} \frac{GM_1 M_2}{r^2} dr = -GM_1 M_2 \int_{r_1}^{r_2} \frac{1}{r^2} dr$$

$$W_g = -GM_1 M_2 \left(-\frac{1}{r}\right) \Big|_{r_1}^{r_2} = \frac{GM_1 M_2}{r_2} - \frac{GM_1 M_2}{r_1}$$

$$U_g = -\frac{GM_1 M_2}{r}$$