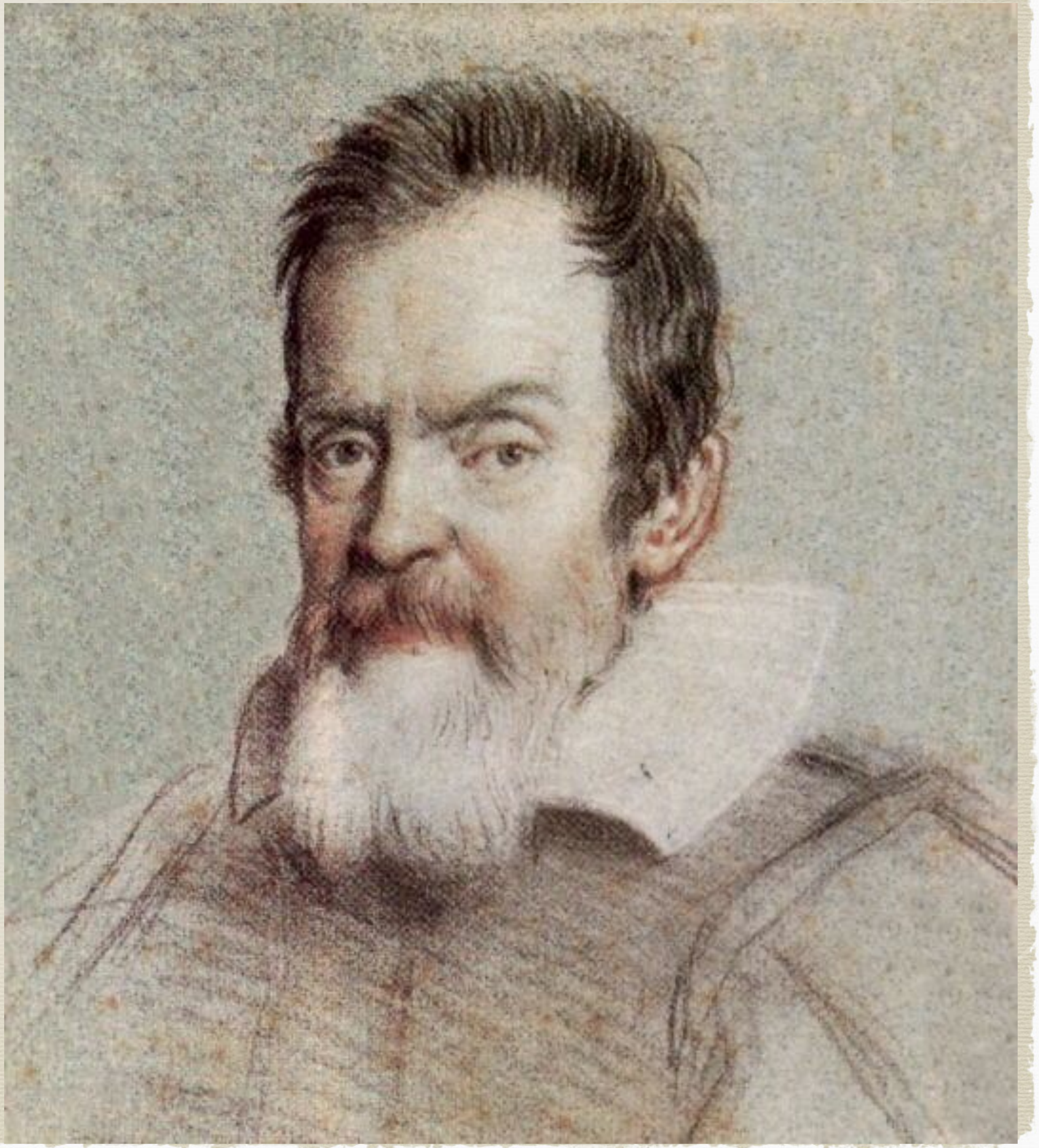
Newton’s Laws

Chapter 4

Galileo Galilei

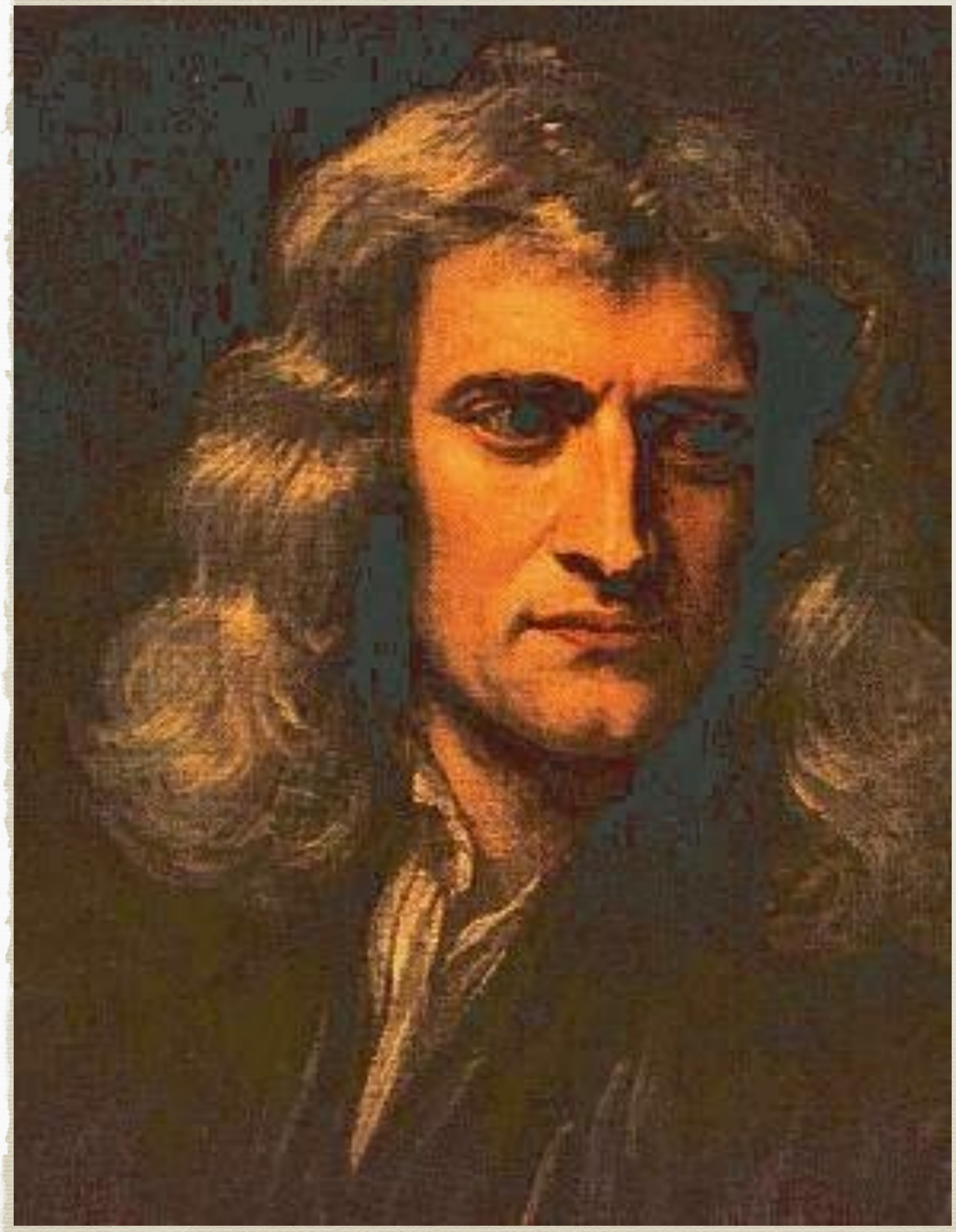
* Galileo was an Italian scientist who lived from to 1564 to 1642.
* He famously dropped objects of different masses and observed that they fell at the same rate.
* He determined that if one could make a frictionless, surface objects would move on it indefinitely at a constant speed.
* He was a proponent of the idea that observation is how one should learn about science. An idea that is central to our understanding of the scientific method.
* He also was the first to point a telescope at the sky and thus started modern astronomy.



Aristotle's Theory

Heavier objects fall faster than lighter ones.

Newton



* Sir Isaac Newton (1642-1727) is the person who really developed physics (and science) as we now know it.
* He developed calculus and used it to study mechanics.
* He postulated 3 laws of motion that describe how objects react to forces.
* He introduced a law of universal gravitation that explained why apples fall and why the Moon orbits the Earth.
* He also worked in optics and the physics of cooling.

History of the Universe - The Big Bang - Newton

Newton’s Laws of Motion

1. *“Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon.”*
2. *“The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.”*
3. *“To every action there is always opposed an equal reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.”*

Newton's 1st Law

* An object in motion stays in motion, and object at rest stays at rest, unless acted upon by a force.
* The normal state of things is to continue doing what they are doing unless something else acts on them.
* This property is called inertia, a resistance to change.

Newton’s 2nd Law

* The second law is that if there is an acceleration it is caused by a force.
* The acceleration is in the direction of the force and proportional to it.
* The acceleration also depends on the objects mass. The more massive an object is the greater force is required to give it acceleration.
* Mass is not weight. Weight is a force. Mass is your resistance to begin accelerated.

Newton’s 3rd Law

* When ever a force is applied, there is always and equal and opposite force.
* This is not always obvious, but according to Newton it must be true.
* If the Earth pulls on the Moon, the Moon pulls on the Earth.
* If you push against the ground, then the ground pushes back against you.

Newton's Laws of Motion

1 $$\frac{d\vec{v}}{dt} = 0, \qquad \text{if} \sum \vec{F} = 0$$

2 $$\sum \vec{F} = m\vec{a}$$

3 $$\vec{F}_{ab} = -\vec{F}_{ba}$$

Unit of Force

* The MKS unit of force is appropriately named the Netwon.

* $1\ N = 1\ kg \cdot m/s^2$

* While this may seem like a weird unit it is just what you get from F=ma. Dimensional analysis will tell you that m has units of kg and a has units of m/s^2, so force must have units of $kg \cdot m/s^2$ or N.

Example 4-3

* What force is required to bring a 1500-kg car to rest from a speed of 100km/h within a distance of 55m?

known

$x_o = 0$ $x = 55m$

$v_o = 100km/h = 27.8m/s$

$v = 0$

$m = 1500kg$

unknown

F= ?

a = ?

physics

F = ma

$$v^2 = v_0^2 + 2a(x - x_o)$$

$$=> a = \frac{-v_0^2}{2x} = \frac{-(27.8m/s)^2}{2(55m)} = -7.0m/s^2$$

$$F = ma = (1500kg)(-7.0m/s^2) = \boxed{-1.1 \times 10^4 N}$$

Weight

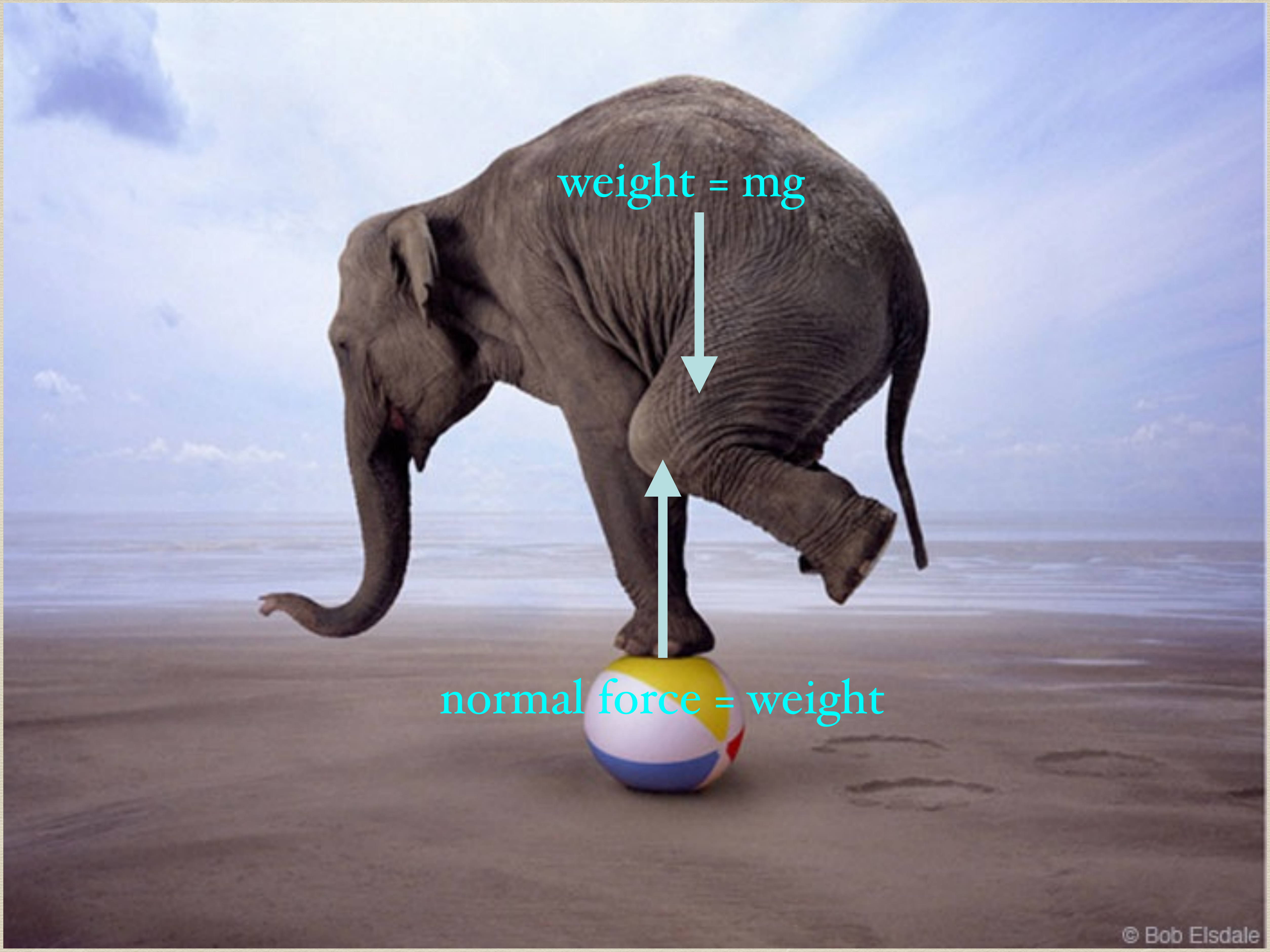
- What is weight? We use the term all the time, but what to we really mean by it.
- Weight can be measured with a scale. If you stand on the scale your weight pushes down on it moving the arrow on a scale for an analog display.
- So weight is a force. It is your mass times the acceleration of gravity.

$$\vec{F}_w = m\vec{g}$$

Normal Force

* When you stand on the floor, does your weight cause you to accelerate downward?
* If not then there must be a force that balances your weight.
* We call this force the normal force, it is the force due to the structure of a material that pushes back on your weight.

$$\vec{F}_N = -\vec{F}_w = -m\vec{g}$$


weight = mg
normal force = weight
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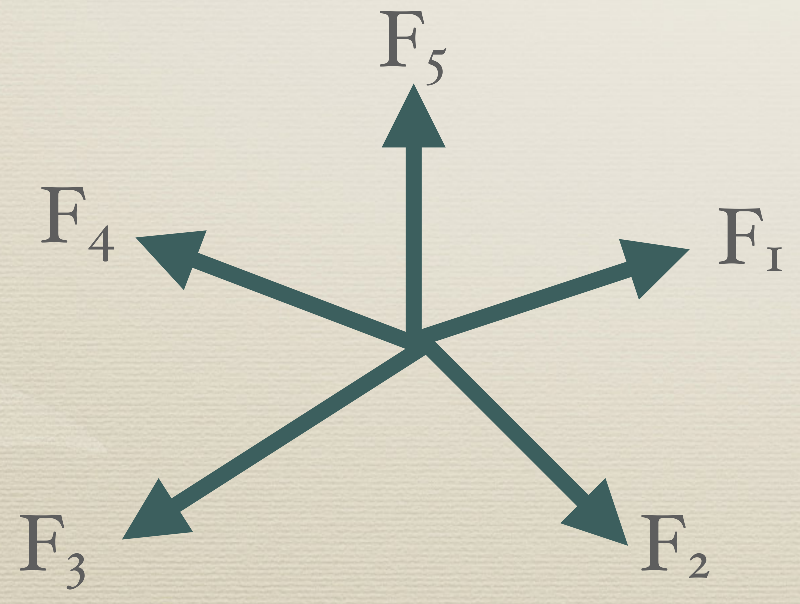
Free Body Diagrams

* Newton's second law tells us the acceleration depends on the **net** force exerted on an object.
* Thus is general we must add up all the forces on an object first, before we can see if the object will accelerate.
* This is called a free body diagram.



Empire Strikes Back

How much force does it take to lift the X-wing?

We can look in Wookiepedia to find that the X-wing fighter is 12.5 meters long, but unfortunately its mass is not given.

Following XKCD we can scale a F-22 fighter jet which is 19m long and has a mass of 19,700kg to give the X-wing fighter a mass of

$$(12.5/19)\ (19700) = 12{,}960\text{kg}$$

So the weight of the X-wing fighter is

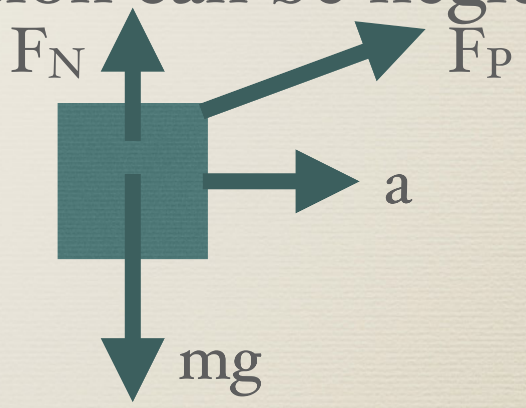
$$mg = (12960\text{kg})(9.81\text{m/s}^2) = 127{,}\ 138\ \text{N}$$

So Yoda using the Force can exert a force of roughly ~130,00 N.

Example 4-11

* Suppose a friend asks to examine the 10.0-kg box you were given, hoping to guess what is inside, and you respond, "Sure, pull the box over to you". She then pulls the box by the attached cord along the smooth surface of the table. The magnitude of the force exerted by this person is F_P=40.0 N, and it is exerted at a 30.0° angle. Calculate a) the acceleration of the box and b) the magnitude of the upward force F_N exerted by the table. Assume that friction can be neglected.

known	**unknown**	**physics**
m=10.0 kg	a=?	
F_P=40.0N	F_N=?	
θ=30.0°		



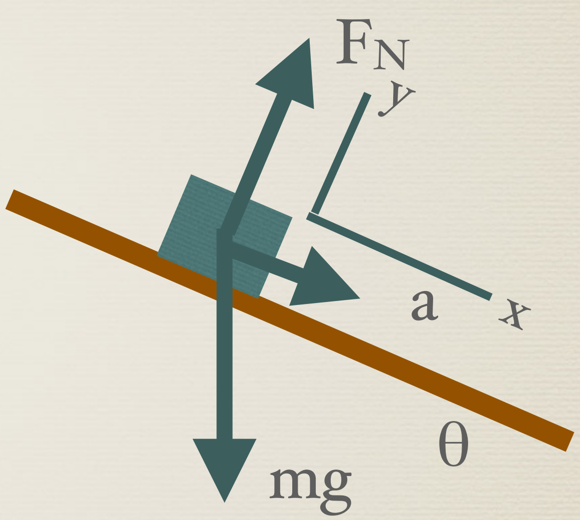
$$F_{Px} = F_p \cos\theta = (40.0N)(\cos 30.0) = 34.6N \qquad F_{Py} = F_p \sin\theta = (40.0N)(\sin 30.0) = 20.0N$$

$$a = a_x = \frac{F_x}{m} = \frac{F_{Px}}{m} = \frac{34.6N}{10.0kg} = \boxed{3.46\, m/s^2} \qquad F_N + F_{Py} = mg$$

$$=> F_N = mg - F_{Py} = (10.0kg)(9.80m/s^2) - 20.0N = 98.0N - 20.0N = \boxed{78.0N}$$

Example 4-16

* A box of mass m is placed on a smooth (frictionless) incline that makes an angle θ with the horizontal. a) Determine the normal force on the box. b) Determine the box's acceleration. c) Evaluate for a mass m=10kg and an incline of θ=30°.



known

In this case we aren't worrying about numbers so we can just use letters.

Let's choose x along the incline.

y: $a_y = 0$ $F_N = mg\cos\theta$

x: $F_x = mg\sin\theta = ma_x$ $a_x = g\sin\theta$

$F_N = (10kg)(9.8m/s^2)(\cos 30) = 85N$ $a_x = 9.8\sin 30 = 4.9\,m/s^2$

Homework

* Chapter 5: 21,33,36,40,49,60