

# Physics 103

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September 26, 2007

Newton's Laws – Part 1  
Forces and Motion

# Physics 103

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## Precept Notes

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Forces and Motion – Part 1  
Newton's Laws,  
Motion in 1 Dimension

## Announcements

- Read Knight Chapters 4, 5 and 6.  
The topic is point particle dynamics – the study of motion of objects whose position matters, but not orientation.  
Note that chapter 5 was missing in the syllabus, but we will definitely be covering it!
- Problem set 2a is posted.  
– You do not have to read chapter 8 to solve the last problem. It is an  $F=ma$  problem.
- I will not be available from 11 AM – Noon today due to a meeting. I will have an office hour from 5-6 PM instead.

## What is a Force?

- Start with brief discussion of what is a force....  
Questions to clarify the concept, and what is being modeled by a force.
- Key points – forces model interactions, interactions always occur in pairs (action – reaction), forces add as vectors (experimental fact, required for model, not proven by it). Some forces are more fundamental than others.
- Physicists recognize four fundamental forces: gravity, electricity + magnetism (unified by Einstein), and the strong and weak nuclear forces.

## Surfer

You are surfing a large wave, maintaining a constant height on the leading edge of the wave while it carries you to shore at a steady speed. The net force on you is

- A. uphill – toward the crest behind you.
- B. downhill – toward the trough in front of you.
- C. zero.
- D. horizontal – toward the shore.

Newton I: Constant velocity implies zero net force.

## Car at Rest

A car on earth is at rest.

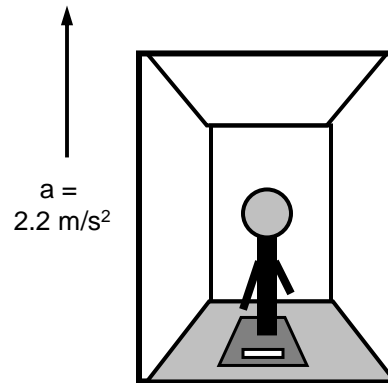
- (a) How are the gravitational pull of the earth on the car and the normal force of the ground on the car related, and why?
- (b) How are the gravitational pull of the earth on the car and the gravitational pull of the car on the earth related, and why?

- (a) The car is in equilibrium, so the net force on the car is zero.
- (b) These are an interaction pair (action, reaction). Newton III

## Weight in an Elevator

An elevator accelerates upward at  $2.2 \text{ m/s}^2$ .

What does the passenger apparently weigh, as measured by the scale in the elevator, if his mass is  $100 \text{ kg}$ ?



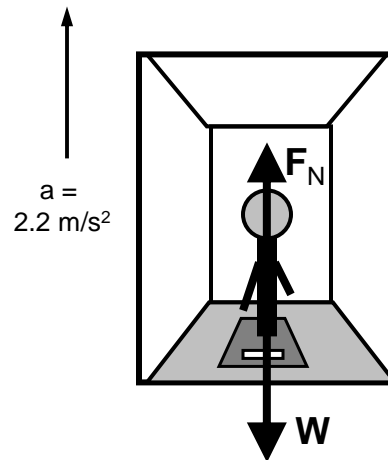
## Weight in an Elevator

The scale measures the normal force on the passenger.

The net force on the passenger is  $F_N - W$ .

Newton's law:

- $F_N - W = ma$ .
- $W = mg$ .
- $F_N = ma + mg$   
 $= (100 \text{ kg})(12.0 \text{ m/s}^2)$   
 $= 1200 \text{ N}$ .



## Comment on Units, Weight

Added in response to questions asked in both classes

Note:  $1 \text{ N} = 1 \text{ kg m/s}^2$  is a *derived* unit of force. It's about  $\frac{1}{4}$  pound.

- Weights are forces, and can be given in units of N or pounds. It is technically incorrect to measure weights in kg, because this is a mass, not a force.
- $1 \text{ kg}$  *weighs*  $2.2 \text{ lb}$ .

## Unit Conversion

Added in response to questions asked in both classes

What is the apparent weight in pounds?

Multiply by conversion factor in such a way that the unwanted units cancel.

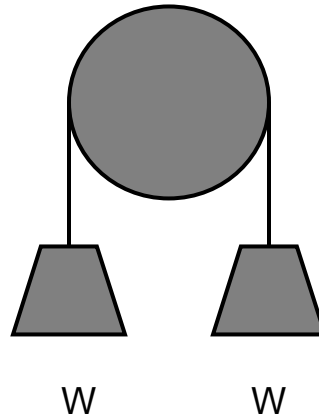
$1 \text{ kg}$  weighs  $mg = 9.8 \text{ N}$ . Therefore, the conversion factor from Newtons to pounds is  $9.8 \text{ N}/2.2 \text{ lb} = 4.45 \text{ N/lb}$ .

Apparent weight =  $1200 \text{ N} / (4.45 \text{ N/lb})$   
=  $270 \text{ lb}$ .

## Tension Question

What is the tension  
in the rope?

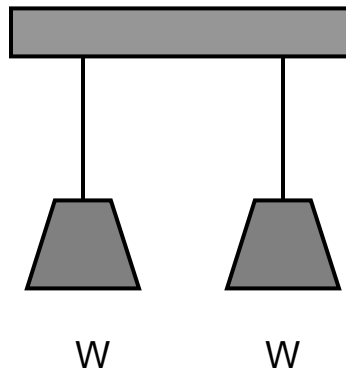
- Is it  $W$  or  $2W$ ?



## Tension Question

Does it make any  
difference if I ask  
for the tensions in  
this diagram?

- Two separate ropes  
hang from the  
ceiling. The  
tensions are both  
clearly  $W$ .

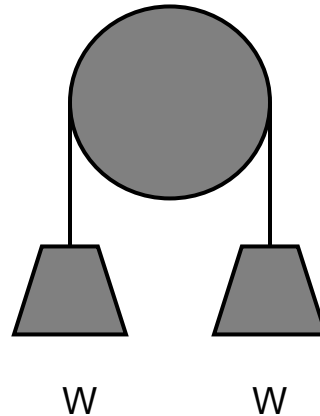


## Tension Question

Physically, these are equivalent situations – either way, each half of the rope supports the full weight!

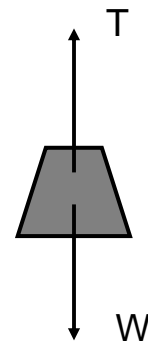
- So  $T = W$ , not  $2W$

Don't add tensions on opposite ends of the rope!!



## Free Body Diagram

- Isolate one object in the situation, and show all forces acting on just that object – don't confuse things by putting any forces acting on other objects. They don't determine this object's motion.
- The object is at rest, so  $T = W$ .



## Prison Break

A prisoner decides to escape from jail by sliding down a rope 20 m above the ground. The rope will break if the tension at any point exceeds 650 N. If the rope has mass 10 kg and the prisoner weighs 75 kg, what is the least speed with which he can reach the ground, starting from rest at the top? [Take  $g = 10 \text{ m/s}^2$ ]

## Prison Break

Is the tension the same throughout the rope?

- No. The rope has mass. Without the prisoner, the tension is 0 at the bottom, and 100 N at the top.

Where will the rope break first?

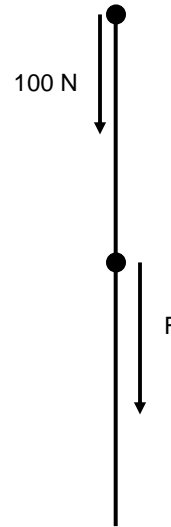
- At the top. So consider the force on the top of the rope.



## Prison Break

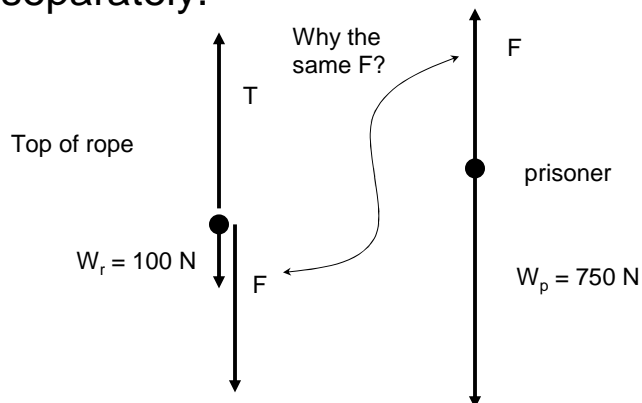
At some point, the prisoner is holding the rope while sliding down. What can we say about the force he puts on the rope at this time?

- Not much – call it  $F$ . It's the frictional force of his hands on the rope.



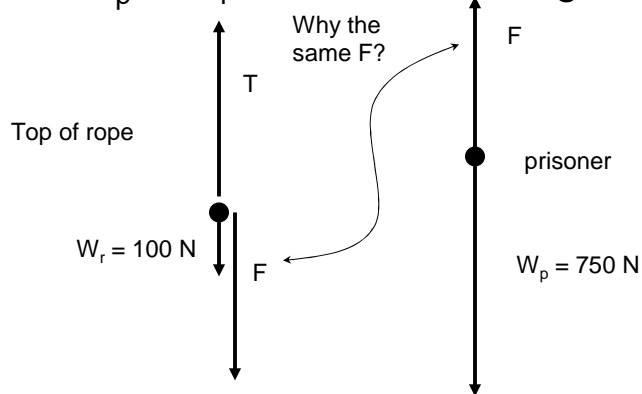
## Prison Break

Draw free body diagrams for the top of the rope and prisoner separately.



## Prison Break

Rope breaks if  $T = 650 \text{ N}$ . Prisoner *must* accelerate, or the tension would be  $T = W_p + W_r = 850 \text{ N}$ , breaking the rope.



## Prison Break

$$T_{\max} = 650 \text{ N} = 100 \text{ N} + F \text{ gives } F_{\max} = 550 \text{ N.}$$

$$M_p a = M_p g - F.$$

$$a = g - 550\text{N}/75 \text{ kg} = 2.67 \text{ m/s}^2 \text{ (minimum)}$$

$$v^2 = 2ah = 2(2.67 \text{ m/s}^2)(20 \text{ m}) = 106.7 \text{ m}^2/\text{s}^2.$$

$$v = 10.3 \text{ m/s} = \text{minimum landing speed.}$$

## Prison Break

This question wasn't used in class.

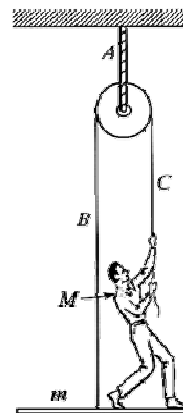
How many g's of acceleration does the prisoner experience if he lands at this speed?

We can find  $a$  using  $v^2 = 2ay$  if  $y$  is the distance over which he decelerates upon hitting the ground. No number was given, but we can reasonably assume that if he lands this fast, his legs will "crumple", absorbing the impact over about half his body height, so  $y \approx 1$  m.

Then  $a \approx v^2/2y = 53$  m/s<sup>2</sup>. Dividing by  $g = 9.8$  m/s<sup>2</sup> gives  $a = 5.4$  g. That's a lot: the prisoner is going to be hurting when the guards pick him up.

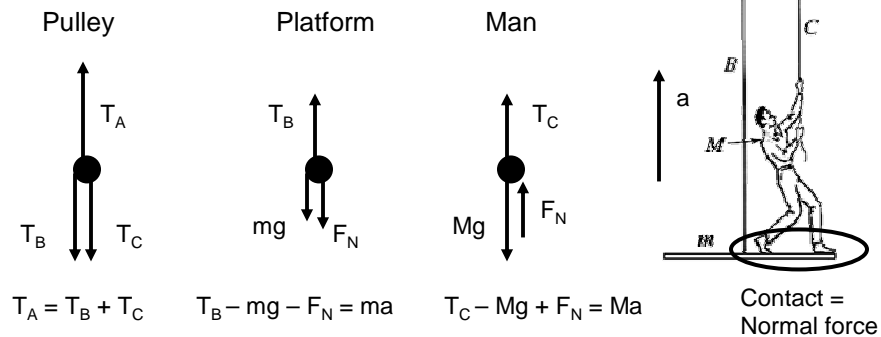
## Platform and Pulley

- A man is pulling himself up a rope with uniform acceleration  $a = 3.0$  m/s<sup>2</sup>.
- The man's mass is  $M = 130$  kg and the platform's mass is  $m = 55$  kg.
- Assume  $g = 10$  m/s<sup>2</sup> and there is no friction or tilting of the platform.
- What are the tensions in each rope segment A, B, C?



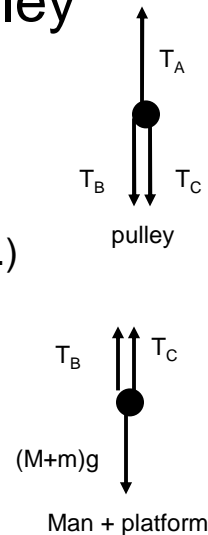
## Platform and Pulley

- What should we isolate for the free body diagrams?



## Platform and Pulley

- Pulley:  $T_A = T_B + T_C$ .
- Considering the man and platform as a single body cancels out the unknown  $F_N$ . (Or add the equations for the platform and man.)  
 $(M+m)a = T_B + T_C - (M+m)g$ .
- Then  $T_A = (M+m)(g+a)$   
 $= (185 \text{ kg})(13 \text{ m/s}^2) = 2400 \text{ N}$ .
- Neglecting pulley mass and friction,  $T_B = T_C = \frac{1}{2} T_A = 1200 \text{ N}$ .



## Platform and Pulley

This question wasn't used in class.

What is the contact force between the man and platform?

- Isolate man or platform. For man,

$$\begin{aligned}F_N &= M(a+g) - T_C \\ &= M(a+g) - \frac{1}{2} (M+m)(a+g) \\ &= \frac{1}{2}(M - m)(a+g) \\ &= \frac{1}{2}(7 \text{ kg})(13 \text{ m/s}^2) = 46 \text{ N.}\end{aligned}$$

