

Problem Set #2 due beginning of class, Tuesday Jan 22. Please state the lens you are using and why.

Very important!. Wednesday of Week 2, we will do our first of two projects. We will take kinematic information from videos of an activity. You will provide graphs of your movement as a function of time – position-t, velocity-t, acceleration-t, net force-t, kinetic energy-t, power-t. You will calculate the maximum power you put out. Please plan this activity in a group of 2-4 people. Please read more about the project on the class webpage on our main class website. Please propose an activity/experiment that your group could do. This project (unlike regular homework) constitutes 5% of your final grade. It will be collected on Tuesday, Week 3.

1. My mass is 70 kg, and the mass of my bike is 10 kg. I'm riding my bike at a constant speed of 15 m/s. At 0s, my displacement is  $x = -10\text{ m}$ . At  $t = 1\text{ s}$ , I apply my breaks and smoothly slow to a stop over a period of two seconds.

- What lens do I use to make these graphs?
- Please graph my acceleration, velocity, and displacement as a function of time. Label the axes correctly.

Then please also find:

- the force exerted by my breaks; *Force of the breaks causes acceleration of the bike and rider*
- and the work done by my breaks and *Energy because the work of the breaks turns kinetic energy into thermal energy*
- the average power. *Rate of change of energy*
- Was energy conserved in this process? How? *YES, energy is always conserved. Kinetic energy was converted to thermal energy. So mechanical energy was "lost" to thermal energy, but the total energy is conserved.*
- Was momentum conserved in this process? How? *There is an outside force (the breaks) on the bike, so the bike's momentum isn't conserved. However the force is between the earth and the bike, so the total momentum of the bike-earth system is conserved. That is, the earth gains the momentum that the bike "lost". OR, momentum is transferred from the bike to the earth via the force of friction.*

a) Kinematics, looking at position as a function of time. Mass won't be considered in graph

b)

$a = \frac{\Delta v}{t} = \frac{0\text{ m/s} - 15\text{ m/s}}{2\text{ s}} = -7.5\text{ m/s}^2$

c) Dynamics:  $F = ma$   
 $M_T = M_P + M_B = 70\text{ kg} + 10\text{ kg} = 80\text{ kg}$   
 $F_b = m \cdot a = 80\text{ kg} \cdot -7.5\text{ m/s}^2 = -600\text{ N}$

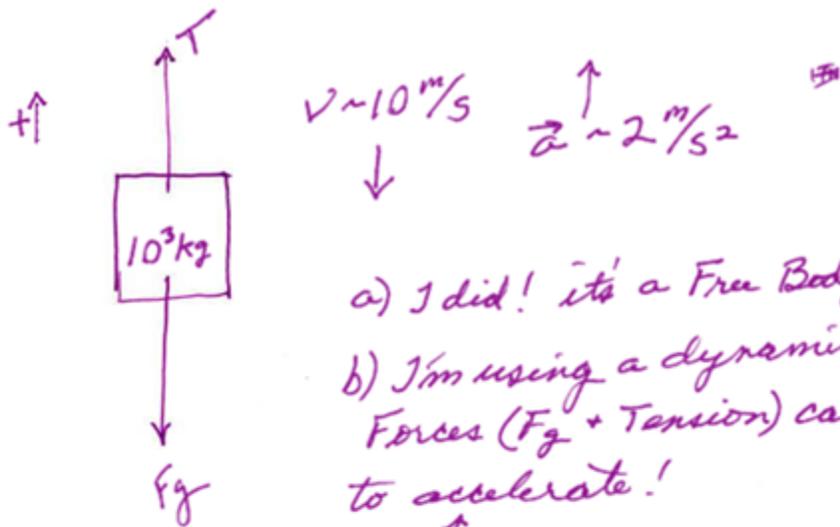
d)  $W = FAX$   
 $\Delta X = \text{Area under } v(t) \text{ curve}$   
 $t = 1.5\text{ s}$   
 $\Delta X = \frac{15\text{ m/s} \cdot 2\text{ s}}{2} = 15\text{ m}$   
 $W = FAX = -600\text{ N} \cdot 15\text{ m} = -9000\text{ Nm}$   
 $P = W/\Delta t = 9000\text{ Nm} / 2\text{ s} = 4500\text{ Nm/s}$   
 (Scalar)  $= 4500\text{ watts}$

e) Kinetic energy was not conserved, for an external force caused a depletion of kinetic energy. However, in general energy was and always is conserved, just not KE, a lot of which was transferred to thermal energy in the brakes

f) lens: momentum  
 Momentum is not conserved because an external force was present

2. Imagine that you are traveling downward in an elevator at a rate of about 10 m/s, but you are slowing down at a rate of 2 m/s every second. The mass of the elevator is 1000 kg (with you in it). I want to find the tension in the cable holding the elevator.

- I bet you already made a drawing and are considering everything involved.
- Please consider all the lenses quickly. Choose one and provide the motivation.
- If you chose dynamics, why would you do this? I mean, what is your motivation?
- What is the complete mathematical relationship between forces and acceleration that define dynamics?
- If you haven't done it, identify these forces with a free body diagram!
- Why is it very (very very) important to identify the direction of acceleration in a FBD?
- Between the tension and the force of gravity, which force is larger or are they the same? Why can you be sure?
- With a forces diagram, show how you add the forces on the elevator to find the resultant force. Find the tension of the cable from which the elevator is suspended.



a) I did! it's a Free Body Diagram!  
 b) I'm using a dynamics lens because forces ( $F_g + \text{Tension}$ ) cause the elevator to accelerate!

c)  $\uparrow$

d)  $\vec{a} = \frac{\sum \vec{F}}{m}$  or  $\sum \vec{F} = m\vec{a}$   
 $\vec{T} + \vec{F}_g = m\vec{a}$

f) Oh! I pick the + direction  $\uparrow$ , in the direction of the  $\vec{a}$ , so I know  $|\vec{T}| > |\vec{F}_g|$  because  $a \uparrow$

g)  $+ T + -F_g = +ma$   
 $T = ma + F_g$   
 $= 2 \times 10^3 N + 10^4 N$   
 $= \underline{\underline{12 \times 10^3 N}}$   
 $\underline{\underline{12 kN}}$

h)  $12,000 \text{ N}$   
 $T$   
 $-F_g = mg = 10^3 \text{ kg} \cdot 10 \text{ m/s}^2 = 10^4 \text{ N}$   
 $\sum \vec{F} = m\vec{a} = 10^3 \text{ kg} \cdot 2 \text{ m/s}^2 = 2 \times 10^3 \text{ N}$

4. You are pushing a car on flat level ground. The mass is 1000 kg, and you are pushing with a force of 500 N. If the car starts with a speed of 5 m/s and you push it forward 20 m,

- a) What is the final speed of the car?
- b) *How about if you push the car in the direction opposite its velocity for 10 meters?*

This question was on an old exam, the solution is meticulously worked out at this website:

<http://sharedcurriculum.peteschwartz.net/wp-content/uploads/sites/3/2019/01/Big-Exam-2-solutions-reflection-2.pdf>

5. Denny Shute ([https://en.wikipedia.org/wiki/Denny\\_Shute](https://en.wikipedia.org/wiki/Denny_Shute)) was a rather tall professional golfer in the 1930s. “Doc” Edgerton ([https://en.wikipedia.org/wiki/Harold\\_Eugene\\_Edgerton](https://en.wikipedia.org/wiki/Harold_Eugene_Edgerton)) was a professor of electrical engineering at MIT who pioneered stroboscopic photography, where an ultra-short flash allowed a process to be illuminated on camera film for such a short time to freeze the process in time. His pictures of a bullet through an apple (<http://www.bbc.com/future/story/20140722-the-man-who-froze-the-world>) for instance made him famous, and when I was a student there in the early 80’s his talks would fill the largest lecture halls with no standing room left. Edgerton photographed Denny Shute hitting a golf ball (<http://artsalesindex.artinfo.com/auctions/Harold-Edgerton-5230133/Densmore-Shute-Bends-The-Shaft-1938>) in the dark with multiple flashes at a frequency of 100 flashes per second.

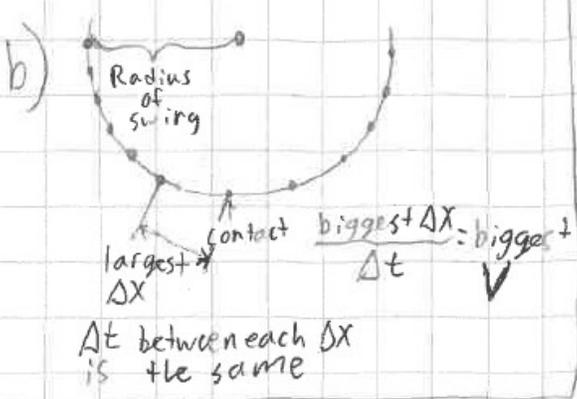
- a) In this photograph of Denny Shute’s drive, how can you perceive speed? What lens do you look at this problem through?
- b) Where is the golf club moving the fastest? How can you tell? Which lens do you use?
- c) Where is the golf club speeding up and slowing down?
- d) How does the speed of the golf ball compare to the speed of the golf club?
- e) There was no flash at the moment that the club hits a golf ball. Where is the club when the ball is at the last two positions before leaving the screen?
- f) Estimate the speed of the golf ball from this picture. Express it in m/s.
- g) Roughly estimate the speed of a golf ball from your experiences. Close your eyes and imagine one being hit, or see a video: <https://www.youtube.com/watch?v=8W89QnvY4Rg>
- h) When the club hits the ball, the ball speeds up. Should the speed of the club change as well? How do you know? What lens do you use?
- i) From looking at the change in speeds of the ball and club on impact, can you make some statement about their relative masses? Can you estimate the ratio of the mass of the club to the mass of the ball?
- j) Please estimate the amount of time that the club is in contact with the ball. You might do this by considering Edgerton’s picture, or a careful look at this video at about 30 s:



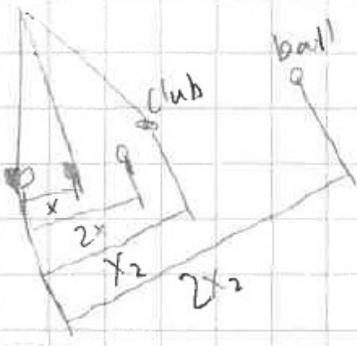
<https://www.youtube.com/watch?v=6TA1s1oNpbk>

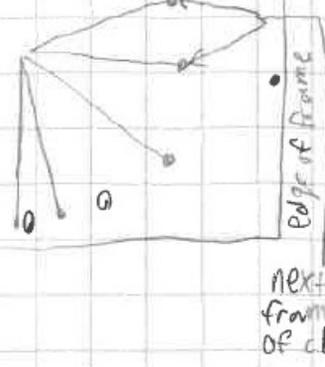
- k) Please calculate the average force between the ball and club during the collision.
- l) Please calculate the average power provided by the club to the ball during the collision

a)   $\frac{\Delta X}{\Delta t} = \Delta V$

b)  Radius of swing  
Contact  
largest  $\Delta X$   
 $\Delta t$  between each  $\Delta X$  is the same  
biggest  $\Delta X =$  biggest  $\Delta t$

c) see f. increase  $f$

d)  club  
ball  
x  
2x  
x  
2x

e)  Edge of frame  
next 2 frames of club

h) equal and opposite force  $F_b = F_c$   
see Q.f  $F_b = m_b a_b$

i) same formula/

a) Kinematics lens: One can perceive speed through time ( $s$ ) is given in the frame-rate and distance can be estimated to other objects whose dimensions are known.

b) Kinematics lens: Since speed is measured in distance over time is moving the fastest is the frame where the largest distance. Answer: Fastest point is the frame before the collision with

c) Kinematics lens: The club is speeding up on Denny's down increasing from the top of his swing, to to the bottom. frame decrease during his follow through, the point at

d) Kinematics lens: Post-collision, the ball covers about two club per frame. The ball also increases in speed after  $t$  speed remains relatively constant after immediately at

e) If an imaginary frame were to be shown during the collision would be at the same position ( $X_0$ ). The next frame, the club  $1/2$  way between  $X_0$  and  $X_1$ . The next frame, the club is about half way between  $X_0$  and  $X_2$ . Ball exits frame

i) If we look closely, it seems the club's decrease in velocity is about  $1/4$  the increase in speed of the ball. Thus the mass of the club should be about 4 times the mass of the ball. If you look this up, is this what you find?

j) I'm going to use my momentum lens because force is the rate of change of momentum, but I could use the dynamics lens too because the normal force between the ball and club accelerates the ball (and the club in the opposite direction). Let's say that the club is in contact with the ball for about 1 ball diameter - let's say 2 cm. I show in the video how I find the speed of the golf ball to be about 80 m/s. Thus, the two are in contact is about  $1/4000$  s, or  $\sim 2.5 \times 10^{-4}$  s.

k) The mass of a golf ball is about 45g or 0.05 kg. If force is the rate of change of momentum, the momentum the ball gains is about 4 kg m/s. In  $1/4000$  of a second, this would correspond to a force of about 16,000 N (The force of gravity on a large car, but only for a short time). If you put a golf ball between two steel plates and drove a large car on the top one, would it cause the ball to squish like it does when it's hit with the club? NOTE, the acceleration of the golf ball when it's hit with the club is way way way more than the acceleration of the club head that we calculate in the video to be about 120 gravities  $\sim 1,200 \text{ m/s}^2$ . The acceleration of the ball is about  $60 \text{ m/s} \cdot 4000/\text{s} \sim 240,000 \text{ m/s}^2$  or 24,000 gravities.

I use an energy lens because power is the rate of change of energy. The ball gains kinetic energy... we calculate about 160 J in  $1/4000$  of a second for an average power of about 0.64 MW... MEGA Watts! That's the power put out by a