Whiteboard: 1/60, f5.6, iso 1000, **WB Use Grey Card**, Manual Audio at level 11, focal length ½ way to ∞. H4n **INPUT @ 95%** gain.

BBB 1/60, f5.6, iso 320, **WB Use Grey Card**, Manual Audio at level 11, focal length ½ way to ∞. H4n **INPUT @ 95%** gain.

BBB Check Horizontal Level & Billy's Lights!! Middle line at bottom 1/3 of desk & remember Billy and Bo chair locations!

Title: Orbital Momentum Conservation

Mr.p: Good morning. Billy, please read the problem and Bo, please translate.

- Billy: [intro] A satellite is in an elliptical orbit. (a) Is its linear momentum conserved? (b) Is its angular momentum conserved?
- Bo: Okay. We have a satellite in an elliptical orbit and, part A, conservation of linear momentum with a question mark, and, part B, conservation of angular momentum with a question mark.

Mr.p: [Satellite in elliptical orbit. a) $¿\sum \vec{p}_i = \sum \vec{p}_f ?$ b) $¿\sum \vec{L}_i = \sum \vec{L}_f ?$] Alright, this seems pretty straight forward. Bobby, please begin solving.

- Bobby: Okay, … we know linear momentum is conserved when the net external force acting on the system equals zero because then the change in linear momentum over change in time equals zero which means the linear momentum of the system is not changing. So, we need to determine if the net external force acting on the system equals zero. The system in this case would be the satellite.
- Billy: … Draw a free body diagram of the forces

acting on the satellite?

- Bobby: Yeah, sure. The forces acting on the satellite in elliptical orbit are … well there is only one force acting on the satellite and it is the force of gravitational attraction pulling it toward the object it is orbiting.
- Bo: The object the satellite is orbiting is called the primary. The satellite orbits around the primary.
- Bobby: Okay. Thanks. The only force acting on the satellite is the gravitational force pulling it towards the primary. … Oh, and that means, because there is only one force, the net external force on the satellite cannot equal zero. Therefore,

the linear momentum of the satellite **does** change and its linear momentum is **not** conserved.

Mr.p: [FBD & $\sum \vec{F}_{\substack{exrternal \\ on\ Satellite}} = \frac{\Delta \vec{p}}{\Delta t} \neq 0 \Rightarrow \sum \vec{p}_i \neq \sum \vec{p}_f$] Great! And Billy, what about angular momentum. Is the angular momentum of the satellite conserved?

- Billy: Well, this is very similar to what we just did for linear momentum. Angular momentum is conserved when the net external torque acting on a system equals zero because then change in angular momentum over change in time equals zero and therefore the angular momentum of the system is not changing. The system is the satellite and we already drew the free body diagram of all the forces acting on the satellite. So, is the net torque acting on the satellite equal to zero?

- Bobby: … We cannot answer that question yet.
- Bo: Why not?
- Bobby: Torque and angular momentum require an axis of rotation and we have not defined an axis of rotation, so we cannot determine torque or angular momentum.
- Bo: Oh, right!
- Billy: Okay. The satellite is revolving around the primary. So, the axis of rotation should be the center of mass of the primary.
- Bo: That assumes the primary is much much

larger than the satellite.

- **Mr.p: (That is fine. You may assume the primary is much much larger than the satellite and therefore the satellite revolves around the center of mass of the primary.)**
- Billy: Alright. The force of gravity always points directly toward the center of mass of the primary which is the axis of rotation. Torque equals the r vector times force times the sine of the angle between the direction of the r vector and the direction of the force. The r vector always points from the primary toward the satellite. The force of gravity acting on the satellite from the primary

always points from the satellite toward the primary. The angle between those two directions is 180 degrees. The sine of 180 degrees equals zero, so, with an axis of rotation at the primary, the net torque acting on the satellite always equals zero so the angular momentum of the satellite about the center of mass of the primary is conserved.

- Bo: Did you really have to identify the axis of rotation so many times?
- Billy: Absolutely. Without a clearly defined axis of rotation, you cannot define torque or angular momentum.
- Bo: Bobby already said that.

- Billy: And I repeated it. Because I am awesome.

Mr.p: [$\sum \vec{\tau}_{\substack{external \\ on\ Satellite \\ with\ AoR\ at\ Primary}} = \frac{\Delta \vec{L}_{system}}{\Delta t} = 0 \Rightarrow \sum \vec{L}_i = \sum \vec{L}_f$ **60 fps?**] Y'all are correct that the linear momentum of the satellite is not conserved and the angular momentum of the satellite, about the axis of rotation of the center of mass of the primary, is conserved. {hear Billy & Bo} I will point out that if we assume the satellite's orbit is circular, linear momentum is still not conserved and angular momentum, about the center of mass of the primary, is still conserved. {hear Billy & Bo} I simply identified the orbit as elliptical because most satellite have nearly elliptical orbits very few satellites have nearly circular orbits. … Thank you very much for learning with me today, I enjoyed learning with you.

- Billy: (Do you hear that? mr.p said the axis of rotation as well.)
- Bo: (yeah, I heard that.)

- Billy: (See, he even said it again.)
- Bo: (I did not see. But I did hear.)
- Billy: (Oh-kay.)