PHYSICS 109: FINAL EXAM PROBLEMS 2009

*The final will be twelve of these: **four from each part**.*

*It will be **pledged**: you must not use any source of information during the exam. You will not need calculators, as you can see.*

When asked for approximate times, the right century is enough.

PART I

1. Explain briefly what features of the Babylonian numbering and measuring systems were superior to ours: sketch the way they represented 1, 2, 10, 25, 60, 5400.

2. Approximately when and where was Thales? What did he contribute to the development of science? How did he measure the height of a pyramid? How did he measure the distance away of a ship?

3. According to the historical record, who first did geometry? And why? And approximately when? Who first approached geometry as a purely *intellectual* exercise?

4. Approximately when and where was Pythagoras? Briefly, what did his followers believe? Why did they think the stars moved across the sky daily? Why did they think numbers related to music?

5. Draw a couple of diagrams to prove Pythagoras' Theorem, that is, reproduce two equal squares containing four identical triangles, as in the flashlet, and explain your proof.

6. Reproduce the Pythagoreans proof that the square root of two is irrational, that is, it isn't a fraction: but do it for 3. Explain why the argument doesn't hold for 9.

7. Approximately when and where was Plato? What institution did he found? What was its purpose? What did it say above the doorway?

8. Describe with sketches Plato's Five Regular Solids. Prove with diagrams that there can only be five. Plato made a specific suggestion to the astronomers as to how they should try to account for the motion of the planets. What was it?

9. Approximately when and where was Aristotle? What was his school called? What were the four elements? Why did things move? What's the difference between what he called "natural motion" and "violent motion"? What were his *quantitative* rules of falling motion?

10. Approximately when and where was Strato? What two arguments did he give against Aristotle's description of natural falling motion?

11. Approximately when and where was Eratosthenes? Describe how he figured out the size of the earth.

12. Approximately when and where was Aristarchus? Explain how he figured out the distance to the Moon.

13. (a) How did Aristarchus try to find the distance to the sun? How accurate was he? What important conclusion could he reach anyway?

(b) How (according to Archimedes) did Aristarchus account for the fact that the stars don't seem to change over the course of a year in the way you'd expect if the Earth is really circling around the sun?

14. How did Archimedes prove the crown wasn't pure gold?

15. Describe how Archimedes found upper and lower bounds to the value of π, and prove it must be greater than 3, but less than 4.

16. Explain Zeno's paradox of Achilles and the tortoise: Achilles runs ten times faster, gives the tortoise a 100 yards start in a 200 yards race—how does he catch up?

17. Explain Zeno's paradox of the arrow: if the smallest time is an instant, an arrow can't move in an instant. But time must be made up of instants, so how can an arrow ever move?

18. Describe with a diagram Ptolemy's basic model for the motion of the inner planets. Does it give a good account of how they are observed to move through the sky? In Ptolemy's time, the phases (shadowing) of the planets could not be observed, but Galileo saw it with his telescope. Do you think that would change Ptolemy's mind if he could have observed it?

19. How did Ptolemy account for the retrograde motion of Mars? How is it accounted for now? If you could see Mars through a telescope, and observe its phases, would they appear any different in Ptolemy's model and Copernicus' model?

20. There will be a "New Moon" December 19th. Two or three days after that, the Moon will be a thin crescent, visible just after sunset. Draw a diagram showing the relative positioning of the earth, the sun and the moon at that phase.

21. (a) Venus is called the evening star sometimes. Does that mean you can never see Venus in the early morning (before sunrise, of course)? Could you ever see Venus at midnight? Explain your answer with a diagram.

(b). At the North Pole, the Pole Star, Polaris, is always directly overhead. Is there anywhere where it is always on the horizon? (At night, of course!) If there is such a place, does it move around the horizon, or stay in the same spot?

22. (a) If you lived on the moon and watched the earth, would you see phases? Would you ever see the earth eclipse the sun? Would you ever see the earth set?

(b). Draw a diagram making clear how an eclipse of the moon happens, and explain why there isn't one every month.

23. Explain why we have seasons, with diagrams. What days mark the beginning of each season? Show where the Earth is on your diagram at the beginning of each season.

PART II

1. When did Copernicus live, approximately? What was his main contribution to science? What reasons did he give for introducing a new model? Why did Galileo's discovery of Jupiter's moons make Copernicus's picture more plausible?

2. How did Galileo estimate the height of mountains on the Moon? Draw a diagram and explain. Approximately, how high were they? How could the Moon still look so round?

3. (a) What physical justification was there for Aristotle's belief that things fell at a uniform speed? What everyday experience did Galileo invoke to suggest that in fact everyone knew better?

(b) Galileo also argued against Aristotle's assertion that something twice as heavy would fall twice as fast by asking how fast a heavy ball tied to a light ball would fall. (See *Two New Sciences*, second selection on my website.) Recount the argument.

4. Reconstruct Galileo's argument that a ball rolling down a ramp would pick up the same speed in losing a given vertical height as a ball simply falling. Explain how timing the ball's motion for certain distances led him to believe it accelerated at a uniform rate.

5. (a) Why didn't Galileo believe in giants? Why can a cat fall through a greater distance safely than a horse can, even though the cat is a lot smaller? Explain your answer.

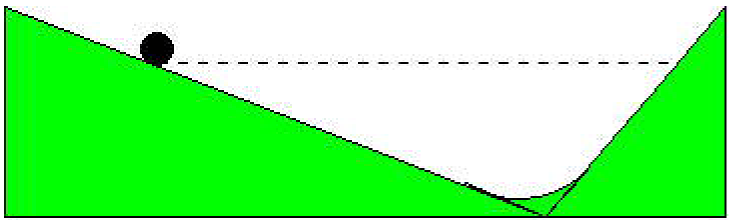
(b) Why are ants several feet long, as seen in movies like "Them" never going to bother us? Why are there no mice in the arctic? Why are lungs so complicated, instead of being like the inside of a balloon, for example?

6. (a) In the movie "Honey I shrunk the kids" the shrunken wife is trapped in her kitchen sink. Galileo would have spotted a mistake in this scenario. What is it?

(b) If a grasshopper could be scaled up to one hundred times its natural length, keeping the same proportions, and it's still able to jump, how high very approximately can it jump?

7. (a) If something falls from rest for two seconds, what is its speed at the end of the two seconds? What was its average speed during the two seconds? How far did it fall? (Note: this question could appear with a different time interval.)

(b). A cannonball is shot horizontally from a cliff top at 100* meters per second. Show on a diagram vectors representing the *velocity* of the cannonball after 1*, 2*, and 3* seconds. Explain with a drawing how these vectors relate to each other and to the acceleration.



8. Draw vectors for the velocity and acceleration of Galileo's two ramp ball at the high point and halfway down each ramp, and at its lowest point. Assume friction is negligible.

9. Draw vectors for the velocity and acceleration of a swinging pendulum at the far point of the swing, at the midpoint, and at a point halfway between the far point and the midpoint.

10. If Newton's cannon were on a mountaintop 7,000 km from the center of the Earth, and we take it that something dropped from rest there falls 5 m in one second, use Pythagoras' theorem to find how fast the cannon must shoot the ball for it to stay in orbit.

11. (a) What three laws of planetary motion did Kepler discover when he analyzed the data?

(b) Suppose Saturn takes 27 years to make one circuit of the Sun, and the earth is about 100,000,000 miles from the Sun, roughly how far from the Sun is Saturn? (Use Kepler's Third Law!)

(*Note: Actually Saturn's period is a little different, but taking 27 years means you don't need a calculator, if you do it right.*)

12. State Kepler's three laws. If an asteroid's orbit is such that its furthest distance from the Sun is twice its nearest distance, how does its speed at the furthest point compare with its speed at the nearest point? Explain how this can be deduced using one of Kepler's laws.

13. (a) State Newton's Laws of Motion. Discuss how they differ from Aristotle's "Laws of Motion", considering both horizontal and vertical motions. How did Newton tie Galileo's two types of motion together?

(b) If you are just standing still, what forces are acting on you? What are the Newtonian reaction forces to those forces?

14. (a) What is Newton's Law of Gravitational Attraction? Explain how relating a falling apple to the Moon in orbit gave him the clue about how gravity between two objects varies with their distance apart.

(b) Show how Newton's Law of Gravitational Attraction explains Kepler's Third Law of planetary motion, assuming the orbits are circles. (It's still true if they're not, but harder to prove.)

15. A car is going around a circular track of radius 100* meters at a speed of 10* meters per second, and at the same time is picking up speed at a rate of 1* meter per second per second. Show on a diagram the magnitude and direction of its acceleration.

16. (a) It's 40,000 km all the way round the equator—so what is the approximate speed (say within 20%) in meters per second of a town on the equator from the Earth's rotation?

(b) This town is going in a circle! So, what's its acceleration? Does gravity provide enough force to keep it firmly on the ground? (A historical objection to a rotating earth was that things would be thrown off.)

17. Describe how the mass of the Earth was first found. Given that, how much more needs to be done to find the mass of the Sun?

PART III

1. Draw a diagram of the Michelson Morley experiment, and explain what they were attempting to measure. Why was the experiment put on a table that could be rotated? About how sensitive was their apparatus for the effect they were trying to detect?

2. (a) What was the emitter theory of light propagation? Why was it suggested, when no-one suggests an emitter theory for sound? What relatively modern experiment showed it to be false? Explain.

(b) How did Einstein generalize an idea of Galileo's to explain the Michelson Morley result?

3. A clock moving past you at a huge speed like 0.8*c* appears to be registering time more slowly. Einstein found out just how slowly by imagining a "light clock". Explain briefly how one would work, and use it to calculate the "slowing down factor"—the time dilation. Is this the only kind of clock that is slowed down by moving at relativistic speeds? Explain your answer.

4. Muons produced above Mt. Washington have a half life of 1.5 microseconds, a time during which light traveling at *c* goes 1500 feet. The muons are traveling at a speed below *c*, yet very large numbers of them make it down to sea level. Explain why this is possible from two points of view: (a) an observer on the mountain, and (b) an imaginary observer traveling with the muons.

5. Explain with an example how it is possible for two observers moving relative to each other both to see the other's clock as running slow: why doesn't this inevitably lead to a contradiction?

6. For a train with length at rest exactly the length of a tunnel, as it goes through the tunnel it will be shorter (it's moving fast) so can be trapped by bandits closing the doors at the ends when it's inside. Assume these are humane bandits who open the door in time for the train to get out again. From the train's perspective, the tunnel is shorter than the train, so explain how this sequence of events appears to a rider in the train. Does the rider ever feel trapped in the tunnel?

7. Give the definition of *momentum* of a moving object. Using Newton's laws of motion—and stating clearly which law or laws you are using—explain how, when two objects interact, the total momentum of the system—the two bodies taken together—stays the same throughout.

8. (a) Explain how Einstein proved that if momentum is always conserved (as he believed it was) then mass must vary with velocity, and give the formula for the variation.

(b) When was this mass variation first observed in a lab?

(c) Guesstimate the mass increase of an airliner on an ordinary flight.

9. What is the definition of work? How much work does it take to lift 2 kg through 20 meters? How does this relate to "potential energy"? How much work does gravity do on the 2 kg mass if it is let fall for two seconds? How does that relate to its speed after two seconds? Explain the connection in this case between potential energy and kinetic energy.

10. (a) If an object is moving at a speed very close to the speed of light, and a force acts on it pushing it in the direction of motion, is $F = ma$ still correct? If not, how must it be changed?

(b) How much work does a force F do in one second at this speed? How does that relate to change in momentum in one second? If the speed really doesn't change perceptibly, how do you account for the change in momentum?

11. A helium atom weighs a little bit less than four hydrogen atoms. Explain how this relates to the Sun's energy.