

Physics 101 Final Exam

December 9, 2002

WHITE EXAM

Select the single best answer for each question, unless otherwise instructed.
Calculators and one page of your own hand-written notes are allowed.

$$g = 9.8 \text{ m/s}^2$$

$$\text{Density of water} = 1000 \text{ kg/m}^3$$

$$\text{Density of air} = 1.25 \text{ kg/m}^3$$

$$1 \text{ Atmosphere} = 10^5 \text{ Pa}$$

$$\text{Boltzmann's Constant } k = 1.381 \times 10^{-23} \text{ Pa m}^3/\text{K}$$

$$\pi = 3.14$$

$$2^{1/2} = 1.41$$

$$\text{Water viscosity} = 0.00100 \text{ Pa s}$$

$$\text{Air viscosity} = 0.0000183 \text{ Pa s}$$

$$\text{Absolute zero} = 0 \text{ K} = -273 \text{ } ^\circ\text{C}$$

$$\text{Stefan-Boltzmann Constant } \sigma = 5.67 \times 10^{-8} \text{ W}/(\text{m}^2 \text{ K}^4)$$

1. The diameter of a pipe is tripled. The volume flow rate of the pipe increases by a factor of
A) 3 B) 9 C) 27 **D) 81**

By Poisuille's Law, the flow rate is proportional to the fourth power of the diameter, $3^4 = 81$.

2. Pendulum A has period 2 seconds. Pendulum B is four times as long as pendulum A. What is the period of pendulum B?
A) 1 second B) 2 seconds **C) 4 seconds** D) 8 seconds

The pendulum period is proportional to the square root of the length, so it is doubled to **4 seconds**.

3. The moment of inertia of a long thin rod is maximum when it is spinning about an axis
A) down the center of the rod lengthwise.
B) through the center of the rod, perpendicular to its length.
C) through the end of the rod, perpendicular to its length.
D) The moment of inertia is a constant, so A, B, and C are all equal.

The moment of inertia is greatest when the lever arm between the pivot and center of mass is the longest.

4. You are riding on a playground swing. As you swing forward, there is a moment when you are directly below the pivot that supports the swing. At that moment, you are
A) accelerating forward. B) not accelerating at all. C) accelerating backward. **D) accelerating upward.**

Your acceleration along the direction of motion is zero at that point. Your centripetal acceleration is directed toward the swing pivot, so it is upward.

5. You are riding a skateboard down a gradual incline. In order to waste as little energy as possible while still maintaining control over your direction of motion, the contact between the sidewalk and the wheels should experience
A) only static friction. B) no friction. C) both static and sliding friction. D) only sliding friction.

Static friction is what keeps the wheel rolling along the ground, so you want to maximize that. You do not want sliding friction, since that would mean the wheel is slipping.

6. In a cartoon, a bunny is surfing on a 10 foot wave crest that is rapidly approaching the shore. The wave crest travels onto the shore intact, with the bunny still on top of it, and continues to carry him across level land for the next twenty miles. This sort of thing can't happen in real life because

- A) wave crests are made from local water and there is no water on land from which to build the crest.
- B) friction between the moving wave crest and the land will slow the crest to a stop in about a mile.
- C) the wave crest will begin to roll like a wheel once it reaches the shore and the bunny will be run over by it as it turns.
- D) the bunny is in an unstable equilibrium and won't be able to stay on top of the crest for more than a mile or two.

The wave travels over the water, while the water just moves locally.

7. Which of the following is not a harmonic oscillator?

- A) A tuning fork with its two tines vibrating rhythmically in opposite directions
- B) A superball bouncing on a ceramic tile floor
- C) A person bouncing gently up and down at the end of a bungee cord, near the end of the ride
- D) A vertical flagpole swaying back and forth

The period of a harmonic oscillator is independent of its amplitude. This is not true for a superball.

8. It is a windy day and there are waves on the surface of the open ocean. The wave crests are 40 feet apart and 5 feet above the troughs as they pass a school of fish. The waves push on fish and making them accelerate. The fish do not like this jostling, so to avoid it almost completely the fish should swim

- A) at the same speed the waves are traveling.
- B) at least 5 feet below the surface of the water.
- C) as close to the surface of the water as possible.
- D) at least 20 feet below the surface of the water.

The depth of a surface wave on the ocean is approximately half its wavelength, so the water is still 20 feet below the surface in this case.

9. When a car crashes into a tree and comes to an abrupt stop, the driver's face and chest collide with an air bag rather than with the steering wheel. The driver's chances of serious injury are reduced by hitting the air bag rather than the steering wheel because the driver transfers

- A) less momentum to the air bag than he would to the steering wheel.
- B) the same amount of momentum to the air bag as he would to the steering wheel, but he does it with larger force due to the air bag.
- C) more momentum to the air bag than he would to the steering wheel.
- D) the same amount of momentum to the air bag as he would to the steering wheel, but he does it with smaller force due to the air bag.

The driver's change in momentum just depends on his mass and velocity change. The airbag affects only the rate at which his momentum changes. By prolonging the impulse, it reduces the force.

10. Why does a fully-inflated basketball bounce better than an under-inflated one?

- A) Air is naturally bouncy.
- B) Air is full of energy.
- C) It stores energy mostly through compression.
- D) It stores energy mostly through surface bending.

The elastic potential energy in a fully inflated ball is stored primarily in the compression of the air inside. In an underinflated ball, it is stored partly in the elastic energy of the bent surface.

11. A flexible chair is supported by metal tubes. When a 600 N person sits on the chair, the chair bends downward 4 cm. What is the chair's spring constant?

- A) 600 N B) 4 cm C) 150 N/cm D) 2400 N*cm

The spring constant is the force divided by the displacement, or $600 \text{ N} / 4 \text{ cm} = 150 \text{ N/cm}$.

12. A rigid cylinder is filled with a gas at a temperature of 300 K and pressure 100000 Pa. The temperature of the gas is then raised to 330 K. What is the new pressure?

- A) 100000 Pa B) 110000 Pa C) 130000 Pa D) Need more information.

By the ideal gas law, when the absolute temperature increases 10%, so does the pressure.

13. How much air weighs the same as 1 liter of water?

- A) 0.00125 liters B) 1.25 liters C) 125 liters D) 800 liters

The data shown at the beginning of the exam show that water is $1000/1.25 = 800$ times as dense as air. Therefore, it takes **800 liters** of air to equal the mass of 1 liter of water.

14. When you get new tires installed on your car the wheels are carefully balanced by placing small weights around the outside of the rim. If one of these weights falls off, your car may vibrate violently when you drive at certain speeds. This vibration occurs for speeds at which

- A) the vibration frequency of the off-balance wheel matches the frequency at which the car likes to vibrate allowing a resonant energy transfer between the two.
B) the rotational kinetic energy of the wheel exactly matches the translational kinetic energy of the car, allowing a resonant energy transfer between the two.
C) the vibrating wheel acts like a harmonic oscillator.
D) the amplitude of the vibrating wheel becomes large enough to overcome the inertia of the massive car.

When the frequency of the off-balance wheel matches the natural frequency of the car, there is a resonance which amplifies both vibrations, since they push on each other with exactly the right timing to increase the amplitude of the vibration.

15. You are sitting on a park bench while your dog walks at the end of a spring-loaded leash. This leash emerges from a plastic container with a handle and can extend up to 5 meters (17 feet) if the dog pulls on it hard enough. As the leash extends outward, a spring in the container stretches. When the dog stops pulling, that spring then retracts the leash back into the container. As the dog pulls the leash outward, stretching the spring, she does work on the leash. During which meter of extension does the dog do the most work on the leash?

- A) During the third meter-when the leash is at the middle of its extension.
 B) During the fifth meter-just before the leash is fully extended.
C) During the first meter-when the leash first begins to extend.
D) The work the dog does is the same during each of the five meters of extension.

Springs obey Hooke's Law: the force is proportional to the extension. Therefore the work done is greatest when the extension is greatest.

16. Ice tea is dispensed from a jug with a faucet at the bottom. As the jug empties, what happens to the speed of flow of tea?

- A) The pressure is lower, so the speed is lower. B) The volume is lower so the speed is lower.
C) The speed is unchanged. D) The speed increases because there is more air in the jug.

By Bernoulli's equation, the speed of flow is proportional to the pressure at the bottom of the jug.

17. A fish floats motionless below the surface of a lake. What is the direction and amount of force the water exerts on it?

- A) Zero B) Down, equal to weight **C) Up, equal to weight** D) Need more information.

If the fish is motionless, the buoyant force exactly matches the weight of the fish.

18. For a given force, doubling the lever arm will change the torque by a factor of

- A) 4 **B) 2** C) 1 (no change) D) 1/2

The torque is equal to the product of the force and the lever arm perpendicular to the force, so doubling the lever arm doubles the force.

19. You enter an elevator on the ground floor of a tall building and push the button for the 10th floor. During your trip upward there are times when you feel your normal weight, when you feel relatively heavy, and when you feel relatively light. The order in which you experience those feelings is

- A) normal, then light, then heavy. B) light, then normal, then heavy.
C) heavy, then normal, then light. D) normal, then heavy, then light.

First, the elevator is accelerating upward, so the acceleration adds to the g you feel, making you feel heavy. When the velocity is constant, you feel your normal weight. Then when the elevator decelerates, the effective g decreases, and you feel light.

20. You and a friend are wondering how your weights compare. To compare your weights you throw the rope over the branch of a tree and each hang from one end of the rope. When you both pick your feet up the rope remains motionless indicating that your weights are exactly the same (neglecting any friction between the rope and the branch). From this observation you know that the tension in the rope is equal to

- A) four times your weight. B) half your weight.
C) twice your weight. **D) your weight.**

Since you are not moving, the tension in the rope must exactly balance your weight. The same is true for your friend.

21. You have two golf balls that differ only in their surfaces. One has dimples, while the other is smooth. If you drop the balls simultaneously from the top of the Eiffel Tower, which will hit the ground first?

- A) Dimpled ball.** B) Smooth ball. C) Both hit at the same time. D) The heavier ball.

The dimpled ball falls faster, since dimples create a turbulent boundary layer which reduces pressure drag. A heavier ball could fall faster due to a higher terminal velocity, but the balls differ only by their surface, so this is not a factor.

22. A rock is dropped from a great height. Ignore air resistance. If the acceleration due to gravity is 32 ft/s^2 , then after 3.0 s the rock's speed is

- A) 32 ft/s^2 **B) 96 ft/s** C) 144 ft/s D) 288 ft/s

The speed is the acceleration times the time, or $32 \text{ ft/s}^2 \times 3.0 \text{ s} = 96 \text{ ft/s}$.

23. A rock is dropped from a great height. Ignore air resistance. If the acceleration due to gravity is 32 ft/s^2 then after 3.0 s the rock has fallen

- A) 32 ft B) 96 ft **C) 144 ft** D) 288 ft

By the answer to 22, the average velocity must be half of 96 ft/s , or 48 ft/s . In 3 seconds, the ball travels a distance of $48 \text{ ft/s} \times 3 \text{ s} = 144 \text{ ft}$.

24. On a windy day you notice that a tall light pole is bent away from its equilibrium position. If the wind speed were to increase the pole would
- A) remain bent by the same amount since aerodynamic drag forces, like sliding friction, are independent of the relative speed of the objects.
 - B) straighten out because the airflow would become laminar and reduce the drag force.
 - C) remain bent by the same amount because the larger drag force will be canceled by a larger restoring force.
 - D) bend further from its equilibrium position because the aerodynamic drag forces that are bending the pole will increase with the speed of the air moving around the pole.

Aerodynamic drag increases with speed. The pole acts as a spring, and bends roughly in proportion to the drag force on the pole, so it bends further when the wind is stronger.

25. All current rockets eject stages or booster rockets as they climb from the earth's surface up to orbit. A rocket that did not eject any stages or booster rockets while climbing from the ground to orbit would
- A) experience too much drag while in orbit and would be unable to remain in orbit for more than a day or two.
 - B) not have anything beneath the rocket on which to push and would be unable to propel itself upward after it left the launch pad area.
 - C) clutter the space around the earth with orbiting debris.
 - D) have to have a launch weight that was about 90% rocket fuel.

The purpose of a multistage rocket is to allow them to eject parts of the rocket as they go, decreasing its mass. That way, they don't have to carry as much fuel. The speed a rocket can attain depends on the ratio of fuel mass to rocket mass. The answer is then, plausibly, (D). Answers (A) and (B) are not true, and (C) is, if anything, backwards, so (D) is the only possible choice. It is, in fact, true.

26. When you blow on a pinwheel, it starts to spin. Even when you aim the air directly toward the wheel's pivot you produce a torque on the wing-like blades and they undergo angular acceleration. This torque is produced by
- A) lift forces on the pinwheel's blades.
 - B) a deflection of the air stream directly away from the pivot.
 - C) the buoyant force due to the high pressure air hitting the blades of the pinwheel.
 - D) drag forces on the pinwheel's blades.

The pinwheel blades act like little rotating wings, and the torque is caused by the lift force of the air blowing over the blades. The answer is then (A). (B) cannot be right, because forces directed away from the pivot produce no torque. (C) makes no sense at all, and drag forces act the wrong way.

27. The longest vertical pipe water can be lifted through by suction on Earth's surface is approximately
- A) 1 m
 - B) 10 m
 - C) 100 m
 - D) It depends on the pump.

The limit is how far atmospheric pressure can lift a column of water: $P = \rho gh$. Using the data given, $h = P/\rho g = 10^5 \text{ N/m}^2 / (10^3 \text{ kg/m}^3 \times 10 \text{ m/s}^2) = 10 \text{ m}$.

28. Why is tungsten most often used as the filament in light bulbs?
- A) It burns hotter than other materials.
 - B) Its emissivity is very high.
 - C) It does not expand much at high temperatures.
 - D) It sublimates slowly at high temperatures.

The main reason is that it sublimates very slowly at high temperatures, so it can emit a relatively white light without burning out too rapidly. The filament material is lost primarily through sublimation.

29. When you jump while standing on a bathroom scale, it briefly reads more than your actual weight. During that moment, it's exerting an upward force on you that is greater than your weight and
- A) you are accelerating downward.
 - B) your velocity is constant but downward.
 - C) your velocity is constant but upward.
 - D) you are accelerating upward.

When there is an upward force on you greater than your weight, you accelerate upward.

30. The curves on bicycle racetracks are steeply banked, so that the inner edge of each curve is much lower than its outer edge. This banking tips the support force that the track exerts on the bicycle wheel toward the center of each turn. That center-directed or centripetal force on the bicycle is important because it
- A) helps the bicycle accelerate inward to complete each turn without skidding.
 - B) it does work on the bicycle during each turn and thus increases the bicycle's energy.
 - C) balances the outward centrifugal force that the bicycle experiences as it completes each turn, so that the bicycle experiences zero net force.
 - D) it does negative work on the bicycle during each turn and thus decreases the bicycle's energy.

Without the bank, all of the centripetal force would have to be transmitted through horizontal static friction on the tires. With the bank, the normal force holding up the bicycle provides some of the centripetal force, so it is not necessary to rely as much on friction, and the bicycle is less likely to skid.

31. Why does a tidal cycle take more than 12 hours?
- A) Earth's rotation
 - B) The Moon orbits the Earth.
 - C) Earth moves around the sun.
 - D) Friction of water with land

Since the Moon orbits the Earth, it takes more than 24 hours for a point on the Earth's surface to come back around under the moon, since the Moon is moving in the same direction. Therefore, tides happen a little more than 12 hours apart, when a point on earth is closest and furthest from the moon.

32. How can you reduce knocking in you car's engine?
- A) Get an oil change
 - B) Use higher-octane gasoline
 - C) Switch to diesel fuel
 - D) Tune the engine so that the gasoline pre-ignites

Knocking is due to pre-ignition, when high compression in the cylinder causes the gas-air mixture to ignite before the spark plug fires and the cylinder is in position to do the maximum work. Higher-octane gasoline spontaneously ignites at higher pressures, and solves this problem.

33. An ordinary incandescent light bulb contains some inert gas inside its glass enclosure because the gas increases
- A) the filament's life while causing a small decrease in the bulb's energy efficiency.
 - B) the bulb's energy efficiency while causing a small decrease in the filament's life.
 - C) the filament's temperature by providing it with extra chemical potential energy.
 - D) both the filament's life and the bulb's energy efficiency.

The inert gas helps to prevent the tungsten particles from subliming as rapidly, so the bulb lasts longer. The gas carries some of the heat away from the filament by convection and conduction, so it decreases the energy efficiency.

34. You fill two identical mugs with coffee, but the coffee in one mug is hotter than that in the other mug. You place the two mugs simultaneously in a microwave oven and turn it on briefly. As a result, you add 1 joule of thermal energy to each mug. Which mug experiences the larger increase in entropy (if any)?
- A) The two mugs experience equal increases in entropy.
 - B) The mug containing the colder coffee experiences the larger increase in entropy.
 - C) Neither mug experiences any increase in entropy.
 - D) The mug containing the hotter coffee experiences the larger increase in entropy

When you add the same amount of heat to two otherwise identical systems, the entropy of the colder system increases more. (This fact and the fact that entropy naturally increases in an isolated system show that heat naturally flows from a hot object to a cold object.)

35. Which of these stars has the hottest surface temperature?
- A) A bluish star
 - B) A yellowish star
 - C) The sun
 - D) A reddish star

Hotter objects emit light with shorter wavelengths. A blue star has a shorter wavelength, and is hotter.

36. It is a warm summer day and you are having lunch outdoors on a patio. A window air conditioning unit hums quietly nearby as it cools an office inside the building. The air conditioner's outside part is emitting the heat

- A) it produces from the electricity it consumes.
- B) that is left over when it converts thermal energy from the inside air into electricity.
- C) it removes from the inside air and the heat it produces from the electricity it consumes.
- D) it produces during its defrost cycle; when it warms up its evaporator to remove ice that forms because of the humidity.

The heat emitted from the outside of an air conditioner has been carried out of the room by the cooling fluid. Since air conditioners cannot be 100% efficient, some of the heat is also left over from running the compressor. The correct answer is therefore (C).

37. You are at the county fair and you are trying to win a stuffed animal by knocking over a stack of heavy milk bottles with a projectile. You have a choice of four projectiles: a 1-kilogram beanbag, a 2-kilogram beanbag, a 1-kilogram superball, and a 2-kilogram superball. Assuming that you can throw each of these projectiles at the same final speed, which one will be most effective at knocking over the milk bottles?

- A) The 2-kilogram superball.
- B) The 1-kilogram beanbag.
- C) The 2-kilogram beanbag.
- D) The 1-kilogram superball.

You want to use the heavier object, since it will carry more kinetic energy, and you want to have the most elastic collision possible, since that will transfer more of the energy to the milk bottles. This means that a heavy superball (A) would be best. A beanbag would have a much more inelastic collision.

38. What is the frequency of a vibration with period 0.02 second?

- A) 0.02 Hertz
- B) 0.02 second
- C) 50 Hertz
- D) 50 seconds

The frequency in Hertz is the reciprocal of the period in seconds, and $1/0.02 \text{ s} = 50 \text{ Hertz}$.

39. Hydrogen is half as dense as helium. Therefore, ignoring the balloon material, the weight of a hydrogen balloon is, compared to a helium balloon of the same volume,

- A) twice as big.
- B) the same.
- C) half as big.
- D) one quarter as big.

The mass is the density of times the volume. Therefore, an equal volume of hydrogen would have **half** the weight of the helium.

40. The buoyant force on a hydrogen balloon is, compared to a helium balloon of the same volume,

- A) twice as big.
- B) the same.
- C) half as big.
- D) one quarter as big.

The buoyant force is equal to the weight of the air displaced by the balloon, which is **the same** in each case.

41. Why does a tennis ball not slow down very quickly when hit?

- A) The fuzz causes turbulence in the boundary layer of air.
- B) The fuzz causes laminar flow in the boundary layer of air.
- C) The ball's aerodynamic shape makes a laminar wake behind the ball.
- D) The Reynolds number is low, so the drag is small.

The turbulent boundary layer reduces pressure drag, and makes the ball slow down less quickly.

42. You are the first person to visit Mars and you've just met a group of Martian school children. One of them asks you how your weight and mass have changed since you left earth. You reply correctly that

- A) your mass is still essentially unchanged but your weight is less than on earth.
- B) your weight is still essentially unchanged but your mass is less than on earth.
- C) neither your weight nor your mass have changed much.
- D) your weight and mass have both changed significantly.

Mass is a measure of the inertia of an object, and doesn't depend on the gravitational field. Your mass would not change on another planet. Weight is the force of gravity on an object, and is equal to the mass times the acceleration due to gravity, which is less on Mars.

43. Why does the tide get so high in the Bay of Fundy?

- A) The channels walls are very high.
- B) The pull of the moon there is especially strong.
- C) Water there has a large potential energy.
- D) There is a natural resonance of water motion there.

The bay has a natural 12 hour period for filling up and emptying, which matches the rate at which it is driven by the tidal force from the Moon. This creates a natural resonance, amplifying the tides.

44. When you blow gently across the top of a particular soda bottle, it emits a tone. The column of air in the bottle is vibrating up and down in its fundamental mode. If you replace the air in the bottle with helium and then blow gently across the top of the bottle, it will emit

- A) a higher pitched tone.
- B) a tone at the same pitch as before.
- C) no sound at all.
- D) a lower pitched tone.

Helium has less mass, so the oscillations will be faster, producing higher frequency sounds from the same wavelengths. (The bottle determines the resonant wavelengths.)

45. A curve ball's path bends to the right as it flies toward home plate because it is experiencing an aerodynamic force to its right. One reason why the ball is experiencing this aerodynamic force is that the ball is spinning and that spin

- A) causes the air to flow more rapidly around the left side of the ball than around the right side of the ball.
- B) exerts a torque on the ball that causes its angular momentum to shift toward the left.
- C) exerts a torque on the ball that causes its angular momentum to shift toward the right.
- D) causes the air to flow more rapidly around the right side of the ball than around the left side of the ball.

The faster flow on the right decreases the pressure on that side, so the ball deflects to the right.

46. You are taking a shower in your dormitory when someone flushes a toilet nearby. The pressure in the cold water line drops and you find yourself showering in what feels like molten lava. This loss of cold water pressure occurs when the flushing toilet lets more cold water flow through the pipes delivering it to the bathroom and the water's speed in those pipes increases. The cold water's faster motion in the delivery pipes reduces its pressure in the shower head because faster moving water

- A) has less pressure than slower moving water.
- B) has less kinetic energy than slower moving water.
- C) has less gravitational potential energy than slower moving water.
- D) loses more energy to viscous drag as it flows through the delivery pipes.

Bernoulli's Principle shows that the water must have lower pressure when it moves faster. (D) is a true statement, but (A) is the best explanation of why increasing the flow to other parts of the plumbing system decreases the pressure overall.

47. If you double the absolute temperature of a light bulb filament, its power output increases by a factor of

- A) 2
- B) 4
- C) 8
- D) 16

The Stefan-Boltzmann Law says that the power output is proportional to the fourth power of the absolute temperature, and $2^4 = 16$.

48. To improve a xylophone's appearance, the orchestra director decides to have it painted. Each xylophone bar is actually a harmonic oscillator that vibrates when struck by a wooden mallet. When bending in its fundamental mode, the bar's middle and ends move in opposite directions. Painting the bar adds mass to the bar without affecting its stiffness, so the paint will

- A) not affect the pitch or sound volume of the bar.
- B) raise the bar's pitch.
- C) lower the bar's pitch.
- D) not affect the pitch of the bar, but will reduce its sound volume.

Increasing the mass slows down the vibrations due to greater inertia, which lowers the pitch of the bar.

49. You are choosing the filament for a light bulb and want it to emit visible light as efficiently as possible when it becomes very hot. You should make that filament

- A) black.
- B) shiny like a mirror.
- C) gray.
- D) white.

A black object is both the perfect absorber and the perfect emitter. A shiny object is the least efficient emitter.

50. You are sleeping outside on a dark, cold night and want to cover yourself with a blanket which will keep you as warm a possible. You should choose one which is

- A) black.
- B) shiny like a mirror.
- C) gray.
- D) white.

A shiny blanket would have the lowest emissivity, so it would cause less heat to be radiated away. A dark colored blanket would radiate the most heat away.