Physics 101 Exam 2

October 16, 2002

WHITE VERSION

Select the single best answer for each question, unless otherwise instructed. No notes are permitted. Calculators are allowed. Ignore friction, air resistance and viscosity unless otherwise instructed.

$g = 9.8$ m/s^2 $\pi = 3.14$

Density of water = 1000 kg/m^3 1 Atmosphere = 10^5 Pa

Absolute zero = 0 K= -273 ^{0} C Boltzmann's Constant = $1.38\text{x}10^{-23}$Pa m^3/K

Bernoulli's principle: $P + \frac{1}{2}\rho v^2 + \rho g h = constant$ along a stream line.

1. If you swing a stone around in a sling in a vertical circle and let it go when it is directly overhead, what is the direction of its flight at the instant it is released?

(a) upward and forward (b) forward and down [✓ (c) straight ahead] (d) upward

When the sling is directly overhead, the velocity vector is pointing straight ahead, parallel to the ground. If you let go of the stone at that time, it will at that instant be directed straight ahead as well, following its velocity vector. Gravity will accelerate the stone downward, but at the instant the stone is released, gravity has had no time to act, so the trajectory is *at that instant* completely horizontal, and straight ahead of the person.

2. If you are riding a roller coaster and want to maximize your feelings of weightlessness during the ride, where is the best place to sit?

[✓ (a) In the back] (b) In the front (c) In the front or back

(d) Anywhere, because eventually all parts of the coaster go as fast.

The feeling of weightlessness is greater the faster you go over the tops of the hills along the track. The front of the roller coaster is moving slowly as it approaches the tops of hills, because it loses energy as it climbs. The back is moving fast at the tops of hills, because the rest of the roller coaster is already descending, pulling on the back. Since the back is moving fastest at the tops of hills, this seat gives the greatest feeling of weightlessness.

3. If ball A bounces twice as high as ball B, how does the coefficient of restitution of ball A compare to that of ball B? Assume equal masses.

(a) It is 4 times as great.

(b) It is half as big.

(c) It is twice as great.

[✓ (d) It is 1.4 times as big.]

The speed the ball bounces is proportional to the coefficient of restitution, which is the ratio of the speed of the ball after the bounce to before the bounce. The height of the bounce is determined by its energy: doubling the energy doubles the height of the bounce. Since the kinetic energy is proportional to the square of the velocity, doubling the energy corresponds to an increase in velocity by a factor of the square root of 2, which is 1.4. Therefore, a ball that bounces twice as high has a coefficient of restitution which is 1.4 times as great.

4. If a bicycle wheel is rolling and starts to fall over to the left, it will turn to the left. This is an example of

(a) Centripetal acceleration

(b) Elastic restoring force

(c) Dynamic instability

[✓ (d) Gyroscopic precession]

5. If you have a bucket of water on the end of a 65 cm string, what is the minimal speed you must swing it overhead to be sure the water will not fall out?

(a) 6.6 m/s

(b) 9.8 m/s

(c) 1.2 m/s

[✓ (d) 2.5 m/s]

For the water to just barely stay in the bucket, its centripetal acceleration must be equal to the acceleration due to gravity. That way, gravity pulls it on a trajectory which just matches that of the bucket. This means $g = v^2/r$. Then $v^2 = g\,r = 9.8\ \text{m/s}^2 \times 0.65\ \text{m} = 6.4\ \text{m}^2/\text{s}^2$, or $v = 2.5$ m/s.

6. The absolute temperature of a gas is proportional to the gas's

(a) average potential energy (b) internal frictional forces
[✓ (c) average kinetic energy] (d) average speed

The absolute temperature is proportional to the average kinetic energy of the gas molecules.

7. If someone is in a small boat in a pond, and then jumps out and floats on the surface of the water, what happens to the water level in the pond?

(a) It goes down. (b) It goes up. [✓ (c) It stays the same.] (d) It could go either way..

The person displaces their weight in water whether in the boat or outside it, as long as the person floats. That means the water level in the pond stays the same. (If the person were to sink instead, then they would displace less than their weight in water, and the water level in the pond would go down.)

8. Suppose your weigh 640 N. When you stand on a trampoline, its springy surface sinks downward 0.12 m. If you bounce on it and it deflects downward 0.30 m, with what force is it pushing up on you?

(a) 2400 N (b) 3260 N (c) 1280 N [✓ (d) 1600 N]

Hooke's Law says that the force on the elastic object (a trampoline here) is proportional to its displacement from equilibrium. In this case, bouncing increases the displacement by a factor of 0.30 m / 0.12 m = 2.5. Therefore, the force pushing up on you is 2.5 times as great as when you just stand there. This gives a force of 2.5 x 640 N = 1600 N.


Sports car


Motorcycle


SUV

9. Which of the following is lists the vehicles shown above in order of **increasing** stability in a high-speed turn?

[✓ (a) SUV, Sports car, Motorcycle]
(b) SUV, Motorcycle, Sports car
(c) Motorcycle, Sports car, SUV
(d) Motorcycle, SUV, Sports car

A two-wheeled vehicle has greater stability in turns because it can lean in the direction of the turn, so that the center of mass is aligned with the force pushing it around the turn. This cancels the torque on the motorcycle and prevents rolling. The force on the wheels of a 4-wheeled vehicle always create a torque around the center of mass of the vehicle when the vehicle turns. This can cause rolling. The torque is greatest if the center of mass is higher compared to how close the wheels are together. Sports cars are low and wide compared to SUVs, so they are more stable against flipping in a high-speed turn.

10. If the temperature of a container of air is increased from 20^{o}C to 100^{o}C, by what factor does the pressure inside increase?

(a) 5.2
(b) 4.0
(c) 2.6
[✓ (d) 1.3]

The initial conditions will be denoted with subscript 1 and the final conditions with subscript 2. The ratio of the pressures will be $P_2/P_1 = T_2/T_1$, where T_1 and T_2 are the *absolute* temperatures corresponding to 20^{o}C and 100^{o}C. Using the above expression for absolute zero gives $T_1 = 293$K and $T_2 = 373$ K. Then $P_2/P_1 = 373\text{K} / 293\text{ K} = 1.3$.

11. Suppose a heavy ball is attached to a light spring and spun around in a circle until the spring stretches 5 cm from its unstretched length. If the ball is swung twice as fast, how much will the spring stretch from its unstretched length?

(a) 20 cm
(b) 10 cm
(c) 7.4 cm
[✓ (d)] more information about the spring is needed to answer this.

By Hooke's law, the amount the spring stretches is proportional to the force on it, or $F = kx$. The force on the spring is equal to the centripetal force on the ball: $F = mv^2 / r$. Here, $r = L + x$ where L is the unstretched length of the spring. Since the forces are equal, the displacement x and velocity are related by $kx = mv^2 / (L+x)$, but L is unknown, so we must know the unstretched length of the spring to solve the problem.

12. Suppose the ball in question 11 is spinning around at 14 rpm when it stretches the spring by 5 cm. If the ball is replaced by one twice as heavy, how fast must it be spun to reach the same extension (5 cm)?

(a) 76 rpm
(b) 28 rpm
(c) 20 rpm
[✓ (d) 10 rpm]

As in the previous problem, the extension of the spring is proportional to the centripetal force, $F = mv^2 / r$. Since the spring stretches the same amount in both cases, the forces are the same, and so are the radii. That means $m_1v_1^2 = m_2v_2^2$, or $v_2^2 / v_1^2 = m_1 / m_2 = ½$. Then the new velocity is the old velocity divided by the square root of 2, or 14 rpm / 1.4 = 10 rpm.

13. Which of these experiments could an astronaut use to tell if he is in space, accelerating at 9.8 m/s^2, or if he is still on the launching pad on earth? Assume he cannot look outside the spacecraft.

(a) He could observe the precession of a gyroscope in the spacecraft.
(b) He could throw a ball up and see where it lands.
(c) He could throw a ball sideways (with respect to the acceleration) and see where it lands.
[✓ (d)] No experiment inside the spacecraft can distinguish these possibilities.

On the launch pad, the astronaut would feel the real force of gravity, with an acceleration of 9.8 m/s2. In space, he would feel no gravity, but the acceleration of 9.8 m/s^2 would create a fictitious force which would make him feel that he is being drawn to the back of the rocket with the same force as if he were on the ground. There is no way to distinguish this fictitious force from a real force unless you can see outside the rocket to tell if it is moving. *All* physics is the same in either case. (This “simple” observation is the basis for Einstein’s theory of gravity, General Relativity.)

14. If a fireman’s hose has a pressure of 5 Atm above atmospheric pressure, how high can the stream go above the hose?

(a) 25 m [✓ (b) 50 m] (c) 75 m (d) 100 m

The height of the stream is given by $\rho gh = P$, where P is the pressure in the hose above atmospheric pressure. This is a result of Bernoulli’s equation, setting the height to be zero at the hose, and neglecting the velocity inside the hose. A pressure of 5 Atm is equal to 5 x 10^5 Pa, so the height is $h = 5 \times 10^5$ Pa / (9.8 m/s^2 x 1000 kg/m^3) = 51 m.

15. In problem 14, if the pressure in the hose is due to water coming from a storage tank, how high is the top of the storage tank?

(a) half the height as the top of the stream in 14.
[✓ (b)] The same height of the top of the stream in 14.
(c) twice the height of the top of the stream in 14.

By energy conservation, the water can rise to the height of the top of the container holding it.

16. If you weigh a rock under water and find that it weighs 2/3 as much as when it is weighed out of water, what is the density of the rock?

(a) 4000 kg/m^3 (b) 6000 kg/m^3 [✓ (c) 3000 kg/m^3] (d) 2000 kg/m^3

If the rock weighs 2/3 as much as outside the water, the water must be supplying a bouyant force equal to 1/3 the weight of the rock. That means that the water the rock displaces weighs 1/3 as much as the rock. Therefore, the rock is 3 times as dense as water, giving it a density of 3000 kg/m^3.

17. When an ideal gas is placed in a container and then heated, the pressure in the container will increase because…

(a) at high temperatures, gas particles collide with the sides of the container more often because they move faster.
(b) at high temperatures, gas particles put more force on the walls of the container each time they hit it, because they are moving faster.
(c) at high temperatures, gas particles have more collisions with each other and push each other apart more.
[✓ (d)] Both (a) and (b) contribute equally.
(e) (a), (b), and (c) are all equally significant.

The more frequent collisions and the greater force per collision against the walls of the container both contribute an equal factor to the pressure when the temperature is raised. If the absolute temperature is doubled, both of these effects increase the pressure by a factor of the square root of 2. Collisions between gas particles are completely neglected for an ideal gas, and are a small effect for most gasses, so (c) is not a factor. Therefore, the answer is (d).

18. A farmer has two wells: a shallow one, 5 m deep, and a deep one, 20 m deep. He can buy either a suction pump for the top of the well, or a submersion pump to put at the bottom of the well. The submersion pump is more expensive. What is the least expensive way the farmer can get two working pumps?

(a) He can buy two suction pumps and place them at the tops of the wells.

[✓ (b)] He can get one of each pump, placing the suction pump on top of the shallow well and the submersion pump in the deep well.

(c) He needs to buy two submersion pumps.

(d) The 20 m well is too deep: neither pump will work in it.

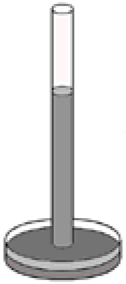
When drawing up fluid using suction, the maximum force on the fluid is the pressure of the atmosphere pressing up from the bottom. (The best you can do is remove all of the pressure from above the fluid.) Then the water can rise to a height given by $\rho g h = 1$ Atm. Using the values given at the beginning of the exam, this gives a maximum height of 10 m that water can be drawn up using suction. The less expensive suction pump will work for the shallow well, but not for the deeper one. A submersible pump can be used to apply force to the water from below and lift it from the bottom of the well. There is no limit to how deep such a pump will work, provided it is strong enough.

19. Absolute zero is the lowest possible temperature because it corresponds to

(a) a system with no internal friction.
(b) a system with zero density.
(c) the total absence of matter in a system.
[✓ (d)] the total absence of motion in a system.

The absolute temperature is proportional to the average kinetic energy of the molecules. Kinetic energy can only be positive (it depends on the square of the velocity), so absolute zero corresponds to every particle being at rest. (In practice, this is an unattainable situation, and absolute zero cannot be reached using any refrigeration technique.)

20. If the density of mercury is 1.4×10^4 kg/m^3, how high will atmospheric pressure push mercury up into an evacuated tube? Assume zero pressure in the tube above the mercury. (This is how mercury barometers work.)



(a) 140 mm
[✓ (b) 730 mm]
(c) 730 cm
(d) 1400 cm

The height of the mercury in the evacuated tube is given by $\rho g h = 1$ Atm. Using the value for 1 Atm at the beginning of the exam and the density $\rho = 1.4 \times 10^4$ kg/m^3 gives $h = 10^5$ Pa / (9.8 m/s^2 x 1.4×10^4 kg/m^3) = 0.728 m, or approximately 730 mm.
The barometric pressure is often given in millimeters (or inches) of mercury.