HRK Multiple Choice Answers

Chapter 1

1. D
2. B. The "80" is exact; it does not have just two significant digits.
3. C

Chapter 2

1. D, B
2. C
3. C, A
4. A
5. C
6. D
7. B, D, E, C
8. C
9. B
10. D
11. D
12. B

Chapter 3

1. D
2. C
3. B
4. A
5. C
6. D
7. B
8. D

9. B
10. C
11. C
12. C
13. B
14. C, B
15. B or D. This depends on the circumstances; all we know is that the moment the parachute opens the drag force is increased, but we don't know by how much. Note that if the parachutist were already at terminal velocity, the answer would certainly be D.
16. C or D. These are equivalent by Newton's third law.

Chapter 4

1. D, D, A
2. B
3. D
4. C
5. E
6. C
7. D, D
8. B, B
9. E, B
10. B
11. B
12. B
13. A. It's impossible to ever have an upward velocity here, because there is no way that air drag can propel you *upward*. The most it can do is put you at rest with respect to the air.
14. C
15. D, C
16. D
17. C, A, D

Chapter 5

1. C
2. D
3. C
4. B
5. D
6. D
7. D. While for many materials $\mu_k < 1$, there are many exceptions. For example, for platinum on platinum, $\mu_k = 3.0$.
8. A, A
9. B
10. D. The real point of the automatic braking system is that if the wheels slip, you can't steer the car, which is even more dangerous.
11. D, D
12. D, none. None of the answers for part (b) are correct; the only correct possibilities would be the total force $\mathbf{N} + \mathbf{W} + \mathbf{f}$, which is a centripetal force, or $\mathbf{N}$. The question writer probably intended $\mathbf{W} + \mathbf{f}$ to be the answer. While this force is always directed radially, it is not always directed radially inward, for example at the lowest point of the circle.
13. C, D.

Chapter 6

1. B or C. This depends on the mass of the horse or quarterback.
2. D
3. C
4. A
5. B
6. C
7. C
8. A
9. B. This is an incredibly unrealistic way to describe a bullet. A lead bullet wouldn't "stick" to anybody besides Superman, it would go through.

10. A
11. A. Specifically, the system of the basketball player and the Earth.
12. B, C, B, D. Since all the collisions that could happen interpolate between completely inelastic and completely elastic, it suffices to consider only those two cases to get the bounds. It also suffices to consider the limiting cases $m_1 \approx m_2$ and $m_1 \gg m_2$ or $m_1 \ll m_2$.

Chapter 7

1. C
2. D
3. D
4. C. The initial velocities have nothing to do with the acceleration of the CM, which is always $a = -g(M-m)^2/(M+m)^2$.
5. B
6. D
7. B
8. C. This is assuming that in both cases, the person's legs deliver the same impulse.
9. A. This can also be done by imagining that the hole is formed by adding additional "negative" mass, a useful trick in general.
10. C
11. B, C
12. C, B
13. A, B

Chapter 8

1. A. The two points are directed along and opposite $\boldsymbol{\omega}$.
2. C
3. B, B, D. In general, n are needed for the location and $\binom{n}{2}$ are needed for the orientation, for a total of $n(n+1)/2$. For the orientation, consider an object made of n orthogonal sticks stuck together. Then n numbers are required to describe the orientation of the first stick, leaving $n-1$ to describe the orientation of the second, and so on.
4. A, because the Earth rotates west to east.
5. C, since $\omega = \alpha t$.

6. D, B. The tangential linear acceleration is $r\alpha$, while the centripetal acceleration is $v^2/r = r\omega^2 = r\alpha^2 t^2$. Hence the total acceleration is $a = r\alpha\sqrt{1+\alpha^2 t^4}$. For small t, a approaches a constant $r\alpha$, but the deviation from this constant grows as t^4. For large t, the centripetal acceleration dominates, giving t^2.

7. A, B, C. This is really an expression for centripetal force.

8. E, C, D.

Chapter 9

1. B. This is an indication that torque is not truly a vector, like displacement and force.

2. D. The lever arm is constant.

3. A

4. D. This is true, though a bit of work to show using only elementary knowledge. With more advanced knowledge, it follows immediately from the statement that the moment of inertia tensor is proportional to the identity matrix.

5. B, B. It doesn't make sense to talk about something being in rotational equilibrium if it isn't in translational equilibrium, as in this case you can always find a point about which the torque vanishes, so some of the answer choices are "not even wrong".

6. B, C.

7. D

8. C

9. B, D, E, E, E. The acceleration of an object with $I = \beta M R^2$ about its center of mass is $a = (g \sin\theta)/(1+\beta)$.

10. D, D, A, A, A. To compare torques, use $\tau = I\alpha = Ia/R \propto \beta M R/(1+\beta)$. Hence in this problem the torque only depends on β.

Chapter 10

1. B, B, C, B. For part (c), one can use $v_\perp = \omega r$ where $v_\perp = 3\,\mathrm{m/s}$ is the tangential speed.

2. C

3. B, C or D. The answer to part (b) depends on whether "will" includes all times t, or only times $t > 0\,\mathrm{s}$.

4. B

5. C

6. A

7. D. In general, this is only true if $\boldsymbol{\omega}$ points along the axis of symmetry.

8. C

9. B. A top may precess even in empty space. See a neat example here.

10. A, B.

11. A, A or C or D. For part (b), the answer is $W/2$ *immediately* after the string is cut, since there is no way for the other string to know about it yet. Afterwards, the wheel begins nutation: while its axis precesses clockwise, it also slightly bounces up and down. In the very beginning the wheel accelerates downward a bit, so the tension is slightly less than W. In the long run, however, the tension averages to exactly W since the wheel doesn't have any net vertical motion. For more about this, see Note 7.2 of Kleppner and Kolenkow.

Chapter 11

1. C

2. A, A

3. B and C

4. C

5. A. With constant power, Fv (or equivalently $\tau\omega$) is constant.

6. B

7. E

8. D, E

9. B

10. C, B

11. D, C

12. A or C. At the very moment they begin accelerating, the answer is C, because the power for both is exactly zero. After a finite time, the answer is A.

13. A. Naively, we use $W = I\omega^2/2$ and maximize I. The coefficients are 2/5, 2/3, 1/2, and 1/2, giving B. However, the work done is *negative*; it does not cost energy to stop something, rather one may harvest energy by doing so. So the answer is actually the choice that minimizes I, which is A.

14. B. Naively, use $W = L^2/2I$ and minimize I. By the same caveat, the answer not A, but B.

15. E, because $W = L\omega/2$.

16. D

Chapter 12

1. C
2. C
3. C
4. A and E.
5. B, C, B
6. C, C
7. D, D. This assumes the radii are negligible for part (b).
8. B, B, B
9. D, D. During the slipping process, energy is not conserved; one must use both linear and angular momentum.
10. A, C

Chapter 13

1. A and D. Potential energy due to the interaction of two things should be regarded as a property of the system containing both things. However, if we can always neglect the motion of the Earth, B may be acceptable.
2. C
3. A
4. C
5. C. The real point here is that, since momentum is a vector, you can't have a net momentum without having *something* moving on average. Contrast this with energy, which can disappear into microscopic thermal motion.
6. B, D. This depends on many things, such as the exact shapes of the two surfaces.
7. C. As stated in the section, it is incorrect to identify the frictional work with $f\Delta x$. However, this *is* the correct expression for the frictional center-of-mass work, which is sufficient for problems where we only care about the center-of-mass motion and not the internal energy.
8. A, B
9. B, B
10. B
11. B. You definitely need at least one direction, because otherwise you can rotate the momenta of C and D about the axis of B's speed.

12. A. While kinetic energy is relative, the net change in kinetic energy in such a process is not, because it is determined by the change in internal energy, which everybody agrees on.

13. C

Chapter 14

1. A

2. C

3. C, D

4. B

5. C. The -2 comes from the binomial theorem applied to the inverse square law.

6. C. The shell theorem still holds, for each individual spherical shell.

7. C

8. D. This can be understood by remembering that gravitational potential change can be found by integrating the gravitational field, which always points inward in this case.

9. C, A, A. This strange behavior, where the kinetic energy goes up as the total energy goes down, can be understood in terms of the virial theorem.

10. A, A, B. For part (a), note that when orbits A and C touch, A has a larger speed, so A has more angular momentum than C. By iterating this process, we find that A has the highest angular momentum. For part (b), note that the energy depends only on the semimajor axis, $E \propto -1/a$. Then the largest (least negative) energy goes with the orbit with the largest semimajor axis, which is A.

    For part (c), note that the highest speed v_1 of an orbit is attained at the distance of closest approach, r_1. Similarly let v_2 be the speed at furthest approach r_2. We want to write v_1 in terms of r_1 and r_2, since those are the quantities we can read from the figure. By angular momentum conservation,

    $$v_1 r_1 = v_2 r_2.$$

    Energy conservation is

    $$\frac{1}{2}mv^2 - \frac{GMm}{r} = E = -\frac{GMm}{2a}$$

    where $2a = r_1 + r_2$. Solving, we have

    $$\frac{v^2}{GM} = \frac{2}{r} - \frac{1}{a}$$

    which is a useful result in general. By angular momentum conservation,

    $$v_1 = \frac{r_2}{r_1} v_2 \propto \frac{r_2}{r_1}\sqrt{\frac{1}{r_2} - \frac{1}{r_1 + r_2}} \propto \sqrt{\frac{r_2}{r_1(r_1 + r_2)}}.$$

    Therefore, if r_2 is fixed, then v_1 is maximized by minimizing r_1. The orbits A, B, and C all have the same r_2, and B has the smallest r_1, so B has the highest speed of the three. And C has a higher speed than D, by considering where their orbits touch. Hence the answer is B. (This is by far the hardest HRK multiple choice question!)

Chapter 15

1. A, B, C; A.
2. A
3. C. It's the product of the area of contact and the air pressure outside.
4. C
5. A, A, A. As the balloon is squeezed, the buoyant force decreases, causing the system to accelerate downward faster and faster.
6. B. (However, to *get* to that lower depth, the diver should let air out of the vest, instead.)
7. C, C, C. In all cases, Pascal's principle and the hydrostatic pressure formula apply.
8. B, B, B, B, A. The cases with acceleration are equivalent to changing the strength of gravity, which doesn't affect the answer since weights and buoyant forces are affected by the same factor. In the last case, increasing the air pressure increases the *air* buoyant force. Since this is now stronger, less water buoyant force is needed, so the block rises up a tiny bit.
9. C, B, B, B. For (b) and (d) the answers are obvious, since the object adds additional weight. For (a), one can see this by noting that the total weight is balanced by hydrostatic pressure at the bottom, which is equal for both buckets. For (c), the total weight is balanced by hydrostatic pressure at the bottom, along with some normal force for the object, so bucket B is heavier.
10. B, A. For (a), the surface tension only depends on the chemical bonds at the surfaces of the bubble, and these don't change with radius. For (b), the pressure in a bubble is atmospheric pressure, plus a contribution proportional to $1/r$ from the inward part of the surface tension force, so the pressure goes down as r increases.

Chapter 16

1. C
2. C, E. However, the answer to (b) is A if the fluid is incompressible.
3. B
4. B, D
5. C. The stream must be in mechanical equilibrium with the surrounding air, and hence has uniform, atmospheric pressure.
6. D
7. B
8. C

Chapter 17

1. B
2. C
3. E, D, E
4. E, C, C
5. B
6. E, D, D
7. B
8. B
9. A, D
10. C
11. A
12. B or C. This is an ambiguous question, because for a damped oscillator there are multiple ways of defining the resonant frequency: the frequency that maximizes the amplitude, that maximizes the peak speed, or that maximizes the power dissipated. These all differ, though in the second case the answer is C.
13. C, A. To show this quantitatively, work in the rotating reference frame where the potential is $V(r) = k(r - r_0)^2/2 - m\omega^2 r^2/2$. The equilibrium separation is the point where $V'(r) = 0$, while the effective spring constant is $V''(r)$ evaluated at that point.