Flipping Physics Lecture Notes:
Mechanics Multiple Choice Solutions
AP® Physics C 1998 Released Exam from the College Board

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Please note:
1) You ***are*** allowed to use a calculator on the Multiple Choice section!! (A change from previous years.)
2) I use the term Free Body Diagram, however, sometimes people use the term Force Diagram instead.
3) UAM means Uniformly Accelerated Motion, in other words, when the acceleration is constant.
4) Remember that you can use g = 10 m/s^2 on the multiple choice. (Probably because you can't use your calculator)
5) When they give a force applied of just F (with no subscript), I always add a subscript, F_a, to identify it a little bit better.
6) They usually use, *f*, for the friction force. To be more clear, I use F_f.

1) The equation for work is, $W = Fdcos\theta$, where F is the force doing the work, d is the displacement of the object and θ is the angle between the Force and the Displacement. In this case the angle given in the problem is the angle between the force applied and the displacement. So the answer is $W = Fdcos\theta$ (B).

2) At the highest point in it's trajectory a projectile has a velocity in the y-direction of zero. (On the way up, the y-velocity is positive and on the way down, the y-velocity is negative, therefore it is zero at the top.)

There is no acceleration in the x-direction in projectile motion; therefore the velocity in the x-direction will remain constant at v_h.

The acceleration due to gravity is g. The acceleration in the y-direction for any object in projectile motion equals –g. Therefore, the answer should be –g, however, that isn't one of the choices. So g is the best answer. Therefore the "correct" answer is (E) [I wish the word "magnitude" had been used in the question.]

3) Start by remembering that the slope of a velocity versus time graph is acceleration. Let's split the motion in to three parts:
1. Part 1 is where the object has a constant, positive acceleration.
2. Part 2 is where the object has a constant acceleration of zero and therefore a constant velocity.
3. Part 3 is where the object has a constant negative acceleration.

Also remember that the slope of a position versus time graph is velocity. Walking through the graph from left to right. The initial velocity is zero, therefore the initial slope of the position versus time graph needs to be zero or horizontal: (A), (C) & (E) don't fit this criterion. For part 2 (B) has a constant position, not a constant velocity, therefore it can't be (B). The only answer it could be is (D). We could stop here, however, let's just point out that Part 2 for (D) shows a constant slope on the position versus time graph which means there is a constant velocity, which is correct. Also (D) shows a positive acceleration for Part 1 and a negative acceleration for Part 2.

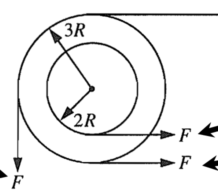
4) $x = t^3 - 6t^2 + 9t$ (note: this assumes t_i = 0) & F_{net} = 0, t = ?

Newton's 2nd law states: $\sum \vec{F} = m\vec{a}$, so $\sum \vec{F} = m\vec{a} = 0 \Rightarrow \vec{a} = 0$ & acceleration is the 2nd derivative of position as a function of time. (Because this is all in the x-direction, we can drop the vector notation.)

$$0 = \frac{d^2x}{dt^2} = \frac{d^2}{dt^2}\left(t^3 - 6t^2 + 9t\right) = \frac{d}{dt}\left(3t^2 - 2\cdot 6t + 9\right) = \frac{d}{dt}\left(3t^2 - 12t + 9\right) = 6t - 12 \Rightarrow 6t = 12 \Rightarrow t = 2\sec$$

Correct answer is (B)

5)



Limber up and use the Right Hand Rule to find the direction of the torque. For F_1 for example: start at the Axis of Rotation (AOR) or in the middle of the wheel. Using your right hand, point your fingers along the lever arm or directly to the left and curl your fingers in the direction of F_1. Your thumb points out of the page, which is defined as positive. For F_2: start at the AOR and point your fingers along the lever arm, which is straight up the page and then your fingers in the direction of F_2. Your thumb points into the page, which is defined as negative. For F_3 & F_4: start at the AOR and point your fingers along the lever arm, which is straight down the page and curl your fingers in the direction of F_3 & F_4. Your thumb points out of the page, which is defined as positive.

$$\sum \tau = \tau_1 - \tau_2 + \tau_3 + \tau_4 = r_1 F_1 \sin\theta_1 - r_2 F_2 \sin\theta_2 + r_3 F_3 \sin\theta_3 + r_4 F_4 \sin\theta_4$$

All the angles between the lever arms, r, and the Forces, F, are 90° and sin(90°) = 1

$$\Rightarrow \sum \tau = r_1 F_1 - r_2 F_2 + r_3 F_3 + r_4 F_4 = (3R)F - (3R)2F + (2R)F + (3R)F = (RF)(3 - 6 + 2 + 3) = 2RF$$

The answer is (C)

6) The equation for the velocity of the center of mass of an object rolling without slipping is $v_{cm} = R\omega$.
The equation for the magnitude of momentum is $p = mv$. So: $p = mv = mR\omega$. The answer is (A)

7) There are no other field forces mentioned and nothing is touching the ball, so there are no contact forces. Therefore, the only force that acts on the ball is the gravitational field force. Newton's Universal Law of Gravitation (or the Big "G" Equation) is: $F_g = \frac{Gm_1 m_2}{r^2}$ (Magnitude only)

The two masses would be the masses of the ball and the asteroid. r is the distance between the center of masses of the asteroid and the ball. As the ball moves up, r, increases and therefore 1/r decreases, therefore F_g decreases. The answer is (A)

8) $\sum F_y = ma_y \Rightarrow F_g = \frac{Gm_1 m_2}{r^2} = ma_y \Rightarrow \frac{Gm_{ball} m_{asteroid}}{r^2} = m_{ball} a_y \Rightarrow a_y = \frac{Gm_{ball}}{r^2}$

$a_{asteroid\ surface} = \frac{Gm_{ball}}{R_{asteroid}^2}$ & $a_{top} = \frac{Gm_{ball}}{(2R_{asteroid})^2} = \frac{Gm_{ball}}{4R_{asteroid}^2} = \frac{1}{4}\left(\frac{Gm_{ball}}{R_{asteroid}^2}\right) = \frac{1}{4} a_{asteroid\ surface}$ The answer is (D)

9) $\frac{d^2x}{dt^2} = -9x$ & the equation that defines simple harmonic motion is $\frac{d^2x}{dt^2} = -\omega^2 x$, therefore:

$\omega^2 = 9 \Rightarrow \omega = 3\frac{rad}{s}$ & $\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi\ rad}{T} \Rightarrow T = \frac{2\pi}{\omega} = \frac{2\pi}{3}\sec$ The answer is (D)

Note: The dimensions work out like this: $T \Rightarrow \frac{rad}{rad/s} \Rightarrow \frac{rad}{rad} \cdot \frac{s}{1} = \sec$

Also: I know the equation $T = \frac{2\pi}{\omega}$ is on the equation sheet, however, I prefer to memorize as little as possible and it is easy to remember that something rotates 2π radians during one period.

10) $T = 2\pi\sqrt{\frac{L}{g}} \Rightarrow \frac{T}{2\pi} = \sqrt{\frac{L}{g}} \Rightarrow \frac{T^2}{4\pi^2} = \frac{L}{g} \Rightarrow g = \frac{4\pi^2 L}{T^2}$ & $g_{Earth} = \frac{4\pi^2 L}{1^2} = 4\pi^2 L$

$g_{Planet} = \frac{4\pi^2 L}{2^2} = \frac{4\pi^2 L}{4} = \frac{g_{Earth}}{4}$ The answer is (A)

11) Satellite with mass, M. Circular orbit radius, R. and constant tangential speed, v.

I. $v_t = r\omega \Rightarrow \omega = \frac{v}{R}$ (I is true)

II. $a_t = r\alpha$ & $\alpha = \frac{\Delta\omega}{\Delta t}$ and if the tangential velocity is not changing and the radius is not changing, then the angular velocity is changing and therefore the angular acceleration, α, is zero. Therefore the tangential acceleration is zero. (II is true)

III. $a_c = \frac{v_t^2}{r}$ is the equation for centripetal acceleration. The tangential velocity and the radius are not changing therefore the *magnitude* of the centripetal acceleration is not changing. (III is true)

The answer is (E). Notice that this question would be a lot more fun if the word "magnitude" had been left out of statement III. In other words: "The centripetal acceleration is constant". Because then the correct answer would be that I and II are true because III would be false because the direction of the centripetal acceleration is always "center seeking" or inward and therefore the centripetal acceleration is always changing. However, the magnitude of the centripetal acceleration is constant.

12) This is a classic *Area "Under" the Curve* question. Impulse, $J = \int F\,dt = \Delta p$. And the integral is the Area "Under" the Curve. I put "area" in quotes because technically it is the area between the curve and the horizontal axis where area above the axis is positive and area below the axis is negative. Therefore the total *area "under" the curve* in this graph is zero. The answer is (C).

13) This is an inelastic collision where all forces are internal and therefore momentum is conserved.
Let's identify m as m_1 and 2m as m_2.

$$\sum \vec{p}_i = \sum \vec{p}_f \Rightarrow \vec{p}_{1i} + \vec{p}_{2i} = \vec{p}_{tf} \Rightarrow m_1 v_{1i} + m_2 v_{2i} = m_t v_{tf} = (m_1 + m_2) v_{tf}$$

$$\Rightarrow (m)(v) + (2m)\left(\frac{v}{2}\right) = (m + 2m) v_{tf} \Rightarrow mv + mv = 3mv_{tf} \Rightarrow 2v = 3v_{tf} \Rightarrow v_{tf} = \frac{2v}{3}$$ The answer is (C)

14) k = 100 N/m, L_i = 0.07 m, m_{disc} = 1 kg, Uniform Circular Motion, i.e. α = 0,
L_f = 0.1 m (spring is stretched 0.03 m, so x = 0.03 m)
no friction. There are 3 forces in the free body diagram: Force Normal is up, Force of Gravity is down and the Spring Force is inward.

$$\sum F_{in} = F_{spring} = ma_c \Rightarrow F_{spring} = kx = (100)(0.03) = 3N$$ Answer is (B)

Please note that the equation for F_{spring} is: $F_{spring} = -kx$ and that negative shows that the force of the spring is opposite the direction of displacement. And, when an object is moving in a circle, the "in" direction is always positive. Therefore when we sum the forces in the "in" direction, the Force of the Spring is positive because it is in the "in" direction and we use the magnitude of the equation for the Force of the Spring.

15) Remember that the angle in the work equation is the angle between the force doing the work and the object's displacement. $W = Fd\cos\theta = F_{spring} d \cos(90) = 0$ Answer is (A).

16) There is no mention of non-conservative / friction forces; therefore we are to assume that we can use Conservation of Energy.

$$ME_i = ME_f \Rightarrow U_i = U_f + KE_f \Rightarrow 3U_o = U_o + \frac{1}{2}mv_f^2 \Rightarrow \frac{1}{2}mv_f^2 = 2U_o \Rightarrow v_f = \sqrt{\frac{4U_o}{m}}$$ Answer is (C)

17) $U(r) = br^{-\frac{3}{2}} + c$ again, it doesn't mention it, however, we are to assume that this is a conservative force and therefore we need to use the equation for a conservative force that seems comes up on every AP® Physics C test and is not on the provided equation sheet: (in this problem our position variable is *r* not *x*)

$$F(x) = -\frac{dU}{dx} \Rightarrow F(r) = -\frac{dU}{dr} = -\frac{d}{dr}\left(br^{-\frac{3}{2}} + c\right) = -\left(-\frac{3}{2}\right)\left(br^{\left(-\frac{3}{2}-1\right)}\right) = \frac{3}{2}br^{-\frac{5}{2}}$$ Answer is (A)

18) L = 3 m, A = 10°, U_{max} = 10 J, KE = ? (when U = 5 J): Again Conservation of Energy:

$$ME_i = ME_f \Rightarrow U_i = U_f + KE_f \Rightarrow 10 = 5 + KE_f \Rightarrow KE_f = 5J$$ Answer is (B)

19) m_e = 1000 kg, a = constant, v_f = 0, Δy = -8 m, T = 11000 N, v_i = ?

In our Free Body Diagram the Tension force is up and the force of gravity is down. Use Newton's 2nd law to find the constant acceleration and then UAM to find the velocity initial.

$$\sum F_y = T - F_g = T - mg = ma_y \Rightarrow a_y = \frac{T}{m} - g = \frac{11000}{1000} - 10 = 11 - 10 = 1$$

& $v_f^2 = v_i^2 + 2a_y\Delta_y \Rightarrow 0^2 = v_i^2 + 2(1)(-8) \Rightarrow v_i = \sqrt{16} = 4\frac{m}{s}$ Answer is (A)

20) D is Diameter of the orbital circle. Mass is M and speed is v. Hmm. I like this one. Where to start doesn't leap out at you. Let's start by summing the forces in the in direction on one of the two stars and see what happens. The only force in the Free Body Diagram is the Newton's Universal Force of Gravity.

$$\sum F_{in} = F_g = ma_c \Rightarrow \frac{Gm_sm_s}{r^2} = m_s\frac{v_t^2}{r} \Rightarrow \frac{GM}{D^2} = \frac{v^2}{D/2} \Rightarrow \frac{GM}{D} = 2v^2 \Rightarrow v^2 = \frac{GM}{2D}$$ Answer is (B)

Remember that "r" in Newton's Universal Law of Gravitation equation is defined as the distance between the center of masses of the two objects, *not* the radius.

21) Mass of block is m, Force applied is F_a, angle between F_a and horizontal is ϕ, Friction force has a magnitude F_f, a = ?

The free body diagram will have a Force Normal, F_N, up, the Force of Gravity, F_g, down, the Friction Force, F_f to the left and the Force Applied, F_a, to the right and up at an angle of ϕ with the horizontal. Now, you might leap into this one by starting to sum the forces in the y-direction, because, heck, that is where we usually start, however, not this time. We usually start in the y-direction so we can determine the Force Normal because the Force of Friction depends on F_n, however, we already know F_f, so we just jump right to the x-direction.

$$\sum F_x = F_{ax} - F_f = ma_x \Rightarrow a_x = \frac{F_{ax} - F_f}{m} = \frac{F\cos\phi - f}{m}$$ Answer is (D)

22) Now that we are trying to find the coefficient of friction, μ, we do need to sum the forces in the y-direction.

$$\sum F_y = F_N + F_{ay} - F_g = ma_y = m(0) = 0 \Rightarrow F_N = F_g - F_{ay} = mg - F\sin\phi$$

& $F_f = \mu F_N \Rightarrow \mu = \frac{F_f}{F_N} = \frac{f}{mg - F\sin\phi}$ Answer is (E)

23) "This question was not counted when the exam was scored." Yes. Mistakes happen.

24) According to Newton's 3rd law the force that Person 1 exerts on Person 2 is equal in magnitude and opposite in direction to the force exerted by Person 2 on Person 1.

$$\vec{F}_{12} = -\vec{F}_{21}$$

Therefore when both people push on one another they create a mechanical "explosion" where the forces are all internal and cancel one another out. Therefore, using Newton's 2nd Law, we can see that, because the net force on the system is zero, then the acceleration of the system is also zero.

$$\sum \vec{F} = 0 = m\vec{a} \Rightarrow \vec{a} = 0$$

Therefore, because the initial velocity of the system is zero, it will remain zero because the acceleration is zero. Answer is (A)

If you would prefer to use some of the numbers in the problem, you can use the equation for center of mass for a system of particles…

$$x_{cm} = \frac{x_1 m_1 + x_2 m_2}{m_1 + m_2} \quad \& \quad v_{cm} = \frac{dx_{cm}}{dt} = \frac{d}{dt}\left(\frac{x_1 m_1 + x_2 m_2}{m_1 + m_2}\right) = \frac{v_1 m_1 + v_2 m_2}{m_1 + m_2} = \left(\frac{(-2)(120) + (3)(80)}{120 + 80}\right) = 0$$

25) The dancer moves at a constant speed the entire time. Therefore, when the dancer moves in a straight line, he will also be moving at a constant velocity and have zero acceleration. $a_{PQ} = a_{RS} = 0$. As the dancer moves on the semicircles, he may be moving with a constant speed, however, his direction will be changing and he will have a centripetal acceleration inward. Because his speed will be constant, his centripetal acceleration will also be constant. $\left(a_c = \frac{v_t^2}{r}\right)$. The answer is (B)

26) Projectile Motion. Y-direction Knowns: $v_{iy} = 0$, $a_y = -10\ m/s^2$, $\Delta y = -10$ m, $\Delta t = ?$

$$\Delta y = v_{iy}\Delta t + \frac{1}{2}a_y \Delta t^2 \Rightarrow -10 = (0)\Delta t + \frac{1}{2}(-10)\Delta t^2 \Rightarrow -10 = -5\Delta t^2 \Rightarrow \Delta t^2 = \frac{-10}{-5} \Rightarrow \Delta t = \sqrt{2}$$

Time is a scalar and independent of direction so now we can look at the X-direction:

$$v_x = \frac{\Delta x}{\Delta t} = \frac{3}{\sqrt{2}}\frac{m}{s}$$

The answer is (C)

27) We are to assume that this is a conservative force and therefore:

$$F(x) = -\frac{dU}{dx} \Rightarrow dU = -F(x)dx \Rightarrow \int_{U_i}^{U_f} dU = -\int_{x_i}^{x_f}\left(40x - 6x^2\right)dx \Rightarrow U_f - U_i = -\left(\frac{40x^2}{2} - \frac{6x^3}{3}\right)\Bigg]_0^2$$

$$\Rightarrow \Delta U = -\left((20)(2)^2 - (2)(2)^3\right) - \left(-\left((20)(0)^2 - (2)(0)^3\right)\right) = -(80 - 16) - (0) = -64\,J$$

The force in this equation is the $F_{applied}$ which is equal and oppsite to the F_{spring}. Therefore the answer should be the energy stored in the spring which equal and opposite to the energy put into the spring by the Force Applied and is +64 J. (D)

28) $W_{F_g} = F_g d\cos\phi$ The angle in this equation, ϕ, is the angle between the Force of Gravity and the displacement of the object or F_g and d. If we define the angle of the incline to be θ then, on the way down the incline, ϕ = 90 - θ. However on the way up the incline, ϕ = 90 + θ. Therefore if the work done by F_g on the way down the incline is +300 J, then, because $\cos(90-\theta) = -\cos(90+\theta)$, the work done by F_g on the way up the incline must be -300 J. Answer is (C)

[Note: F_g and d are the same going up and down the incline] [Also Note: The angle in the work equation is usually θ and I used ϕ this time. This is because I started by defining the angle of the incline as θ. It might have been good for me to change it, however, I knew you could handle it.]

29) The x and y equations here describe the motion of an object moving in a circle, where A represents the radius and ω represents the angular velocity. Therefore the acceleration of the object is a centripetal acceleration where: $a_c = r\omega^2 = (1.5)(2)^2 = 6\frac{m}{s^2}$ Answer is (E)

If you didn't recognize A as the radius and ω as the angular velocity, you could also solve the problem this way:

$$a_x = \frac{d^2x}{dt^2} = \frac{d^2}{dt^2}\left(A\cos(\omega t)\right) = \frac{d}{dt}\left(-A\omega\sin(\omega t)\right) = -A\omega^2\cos(\omega t) = -(1.5)(2)^2\cos(2t) = -6\cos(2t)$$

$$a_y = \frac{d^2y}{dt^2} = \frac{d^2}{dt^2}\left(A\sin(\omega t)\right) = \frac{d}{dt}\left(A\omega\cos(\omega t)\right) = -A\omega^2\sin(\omega t) = -(1.5)(2)^2\sin(2t) = -6\sin(2t)$$

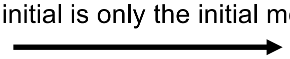
$$a^2 = a_x{}^2 + a_y{}^2 \Rightarrow a = \sqrt{a_x{}^2 + a_y{}^2} = \sqrt{\left(-6\cos(2t)\right)^2 + \left(-6\sin(2t)\right)^2} = \sqrt{36\left(\cos^2(2t) + \sin^2(2t)\right)} = \sqrt{36(1)} = 6\frac{m}{s^2}$$

Note: This uses the trig identity: $\cos^2\theta + \sin^2\theta = 1$ And an easy way to remember this is that it is just Pythagorean's theorem where the hypotenuse has a length of 1.

30) For this object to be in static equilibrium the net torque about the very center needs to equal zero.

$$\sum\tau_{center} = +\tau_{W_1} - \tau_{W_2} = 0 \Rightarrow \tau_{W_1} = \tau_{W_2} \Rightarrow r_1W_1\sin\theta_1 = r_2W_w\sin\theta_2 \Rightarrow (a)(m_1g)\sin 90 = (b)(m_2g)\sin 90$$

$\Rightarrow am_1 = bm_2$ Answer is (B) [use the Right Hand Rule to find directions of torques.]

31) During this collision the momentum is conserved, therefore, because the initial momentum of the 2nd object is zero, the total momentum of the system initial is only the initial momentum of the moving object and is represented by the arrow given in the problem. 

(A) The two vectors appear to cancel.
(B) The two vectors will be twice as long as the original one.
(C) The resultant vector will be in the correct direction, however, will not have enough magnitude.
(D) The resultant vector will be down and to the right.
The only answer that comes close to two vectors that add up to the original vector is (E).

32) Knowns: I, ω_i = 0, ω_f, Δt = T, $\sum\tau$ = ?

$$\sum\tau = I\alpha = I\frac{\Delta\omega}{\Delta t} = I\left(\frac{\omega_f - \omega_i}{T}\right) = I\left(\frac{\omega_f - 0}{T}\right) = \frac{I\omega_f}{T}$$

Answer is (E)

33) Linear form of the average Power equation with a constant force is $\overline{P} = F\cdot\overline{v}$ & the rotational form for a constant torque is $\overline{P} = \tau\overline{\omega}$. Therefore: $\overline{P} = \tau\overline{\omega} = \left(\frac{I\omega_f}{T}\right)\left(\frac{\omega_f + \omega_i}{2}\right) = \left(\frac{I\omega_f}{T}\right)\left(\frac{\omega_f + 0}{2}\right) = \frac{I\omega_f{}^2}{2T}$ Answer is (B)

34) “If limiting cases for large and small values of *t* are considered”… When know when *t* is very large that the object will have reached a terminal velocity, v_t, and the acceleration of the object will be zero:

$$t(\infty) \Rightarrow a = 0 = g - bv_t \Rightarrow bv_t = g \Rightarrow v_t = \frac{g}{b}$$

So let’s look at each answer with t approaching infinity and see which one matches our solution:

(A) $v = \frac{g\left(1-e^{-bt}\right)}{b} = \frac{g\left(1-e^{-(b)(\infty)}\right)}{b} = \frac{g(1-0)}{b} = \frac{g}{b}$ Answer is (A)

(B) $v = \frac{\left(ge^{bt}\right)}{b} = \frac{\left(ge^{(b)(\infty)}\right)}{b} = \left(\frac{g(0)}{b}\right) = 0 \neq \frac{g}{b}$

(C) $v = gt - bt^2 = g(\infty) - b(\infty)^2 = ¿huh? \neq \frac{g}{b}$

(D) $v = \frac{(g+a)t}{b} = \frac{(g+a)(\infty)}{b} = \infty \neq \frac{g}{b}$

(E) $v = v_o + gt = v_o + g(\infty) \neq \frac{g}{b}$

35) Where did they find this ideal, massless spring? I want one too!

No friction. Ideal. No force applied. Conservation of Mechanical Energy!!

$$ME_i = ME_f \Rightarrow KE_{max} = PE_{max} \Rightarrow \frac{1}{2}mv_{max}{}^2 = \frac{1}{2}kx_{max}{}^2 \Rightarrow mv_m{}^2 = kA^2 \Rightarrow k = \frac{mv_m{}^2}{A^2}$$

Answer is (D)