IB Physics
FA8.1 - Rotational Kinematics

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1. A bicycle going 13.5 m/s has 68.0 cm diameter wheels. What is the angular velocity of the wheels in rad/s? in RPM?

2. What is the tangential velocity of a 4.50 cm radius hard drive spinning at 5200. RPM?

3. What time will it take a wheel to speed up from 12.0 rad/s to 47.0 rad/s with an acceleration of 1.40 rad/s/s?

4. A hard drive takes 4.80 s to speed up from rest to 7200. RPM. How many revolutions does it go through in doing this?

5. A car with 0.450 m radius wheels speeds up to 28.0 m/s over a distance of 112 m with an acceleration of 2.60 m/s/s. What is the initial angular velocity of the wheels?

Angular Kinematics problems from 8.1

Tangential Relationships: **$s = \theta r$, $v = \omega r$, $a = \alpha r$**

1. A 0.0760 m diameter (76 mm) skateboard wheel rolls through 137 rotations. What linear distance did it travel? (32.7 m)
2. What is the angular acceleration of a 0.630 m diameter bicycle wheel if it is accelerating linearly at 8.20 m/s/s? (26.0 rad/s/s)
3. A 0.0660 m diameter skateboard wheel travels 12.0 m. How many rotations does it go through? (57.9 rotations)
4. A 0.650 m diameter wheel accelerates at 1.54 rad/s/s. What is the tangential acceleration of the edge? (0.5005 m/s/s)
5. A wheel goes through 143 rotations when it rolls linearly 14.2 m. What is the radius of the wheel? (0.0158 m)

Tangential Relationships with unit conversions: **1 rev or rot = 2π radians, 1 minute = 60 seconds**

6. What is the linear velocity 0.120 m from the center of a grinding disk spinning at 1450 RPM? (18.2 m/s)
7. What is the angular velocity of a 0.920 m radius aircraft tire in rotations/second when it is has a linear velocity of 48.0 m/s? (8.30 rot/s)
8. A merry go round spins at 0.590 rotations/second. What is the tangential velocity 1.80 m from the center? (6.67 m/s)
9. A 0.940 m diameter wheel has a tangential velocity at its edge of 25.0 m/s. What is its angular velocity in RPM? (508 RPM)
10. A hard drive spins at 7200 RPM. What distance from the center has a tangential velocity of 12.0 m/s? (0.0159 m)

Simple Rotational kinematics: **$v = u + at$, $s = (u+v)t/2$, $v^2 = u^2 + 2as$, $s = ut + {}^1/_2at^2$**

11. A drill going 98.0 rad/s decelerates at -1.20 rad/s/s for 15.0 s. What is the final angular velocity in rad/s? (80.0 rad/s)
12. A drill speeds up from rest to 156 rad/s in 5.70 s. Through what angle in radians does it go? (445 rad)
13. A drill goes through 132 radians in 8.80 s slowing to rest. What was its initial angular velocity in rad/s? (30.0 rad/s)
14. A drill speeds up from 11.0 rad/s to 35.0 rad/s in 184 radians. What is its angular acceleration? (3.00 rad/s/s)
15. A drill goes through 526 radians accelerating at 2.58 rad/s/s from rest. What is its final angular velocity in rad/s? (52.1 rad/s)

Rotational Kinematics with unit conversions:

16. A motor speeds up from 1350. RPM with an angular acceleration of 2.90 rad/s/s for 19.0 seconds. Through what angle in radians does it rotate? (3210 rad)
17. A car tire initially rotating at 37.0 rotations per second slows down through 148 rotations in 5.20 seconds. What is its final angular velocity in rotations per second? (19.9 rot/s)
18. A drill speeds up from 680. RPM to 1540 RPM with an acceleration of 1.80 rad/s/s. How many rotations does it go through? (926 rotations)
19. A skateboard wheel speeds up from 5.30 rotations/sec to 12.0 rotations/s in 9.00 seconds. What is the angular acceleration in rad/s/s? (4.68 rad/s/s)
20. A turntable accelerates at 0.835 rad/s/s from rest to 33.3 RPM. What is its angular displacement in radians? (7.28 rad)

Rotational Kinematics with tangential relationships:

21. A car with 0.340 m radius tires going 19.2 m/s decelerates at 1.20 m/s/s for 2.30 s. What is the final angular velocity of the tires? (48.4 rad/s)
22. A car with 0.840 m diameter wheels accelerates from rest with an acceleration of 6.40 m/s/s for 3.50 seconds. Through what angle in radians do the wheels go? (93.3 radians)
23. A 0.110 m radius ball going 5.80 m/s rolls to a stop in 9.70 seconds. What was the angular acceleration of the ball in rad/s/s? (-5.44 rad/s/s)
24. A 0.360 m radius car tire goes from 12.5 rad/s to 36.8 rad/s with a linear acceleration of 3.90 m/s/s. What linear distance does the car travel? (19.9 m)
25. A 0.125 m radius grinding wheel speeds up from 142 rad/s to 259 rad/s in 13.0 s. Through what distance does a point in the edge of the wheel travel in this time? (326 m)

Name__________________________

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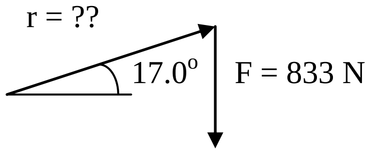
I (about centers): cylinder = $^1/_2mr^2$, ring/point = mr^2, sphere = $^2/_5mr^2$, rod = $^1/_{12}mL^2$ (= $^1/_3mL^2$ about end)

1. A mechanic needs to exert 385 mN of torque. He weighs 833 N and he stands on the handle of his wrench that is making a 17.0° angle above the horizontal. How far from the center must he stand? (Be careful what you use for the angle)



2. What is the acceleration of a flywheel with a moment of inertia of 0.145 kg m^2 if a torque of 2.80 mN acts on it?

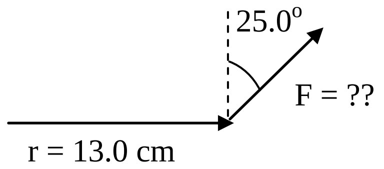
3. A 0.680 m diameter flywheel has a moment of inertia of 0.243 kg m^2. What is the angular acceleration of the flywheel if you exert 4.50 N tangentially at the edge to speed it up?

4. A 0.210 m radius grinding disk is spinning at 1350 RPM. If it goes through 85.0 rotations being brought to rest by a 1.20 N frictional force applied tangentially at its edge, what is the moment of inertia of the disk?

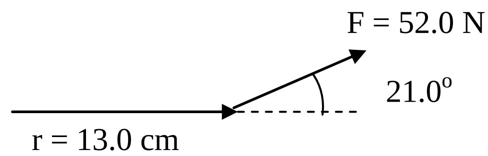
5. A 4.30 m diameter (cylindrical) merry go round going 45.0 RPM stops in 37.0 rotations because of an 8.30 N force applied tangentially at the edge. What is the mass of the merry go round?

Angular Dynamics problems from 8.2

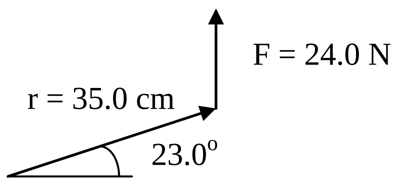
A. What force acting at 25.0° with a line perpendicular to the end of a 13.0 cm long wrench will generate 7.80 mN of torque about the left side of the wrench? (66.2 N)



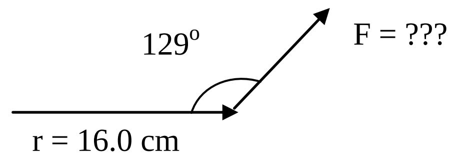
B. Calculate the torque about the left side of the wrench if 52.0 N acts at an 21.0° angle with the end of a 13.0 cm long wrench. (2.42 mN)



C. A 35.0 cm wrench makes a 23.0° angle above the horizontal. What is the torque about the left side of the wrench if a 24.0 N force is exerted vertically upward at the end? (7.73 mN)



D. A force is exerted at an angle of 129° with a 16.0 cm wrench as shown below. Calculate the force needed to create 3.80 mN of torque about the left side of the wrench. (30.6 N)



Moments of inertia: Cylinder: $I = \frac{1}{2} mr^2$, Sphere: $I = \frac{2}{5}mr^2$, Thin Ring or Point Mass: $I = mr^2$

Simple F = ma problems: $\mathbf{\Gamma = I\alpha}$

1. A baton requires 5.70 mN of torque to accelerate at 18.4 rad/s/s about its center. What is the moment of inertia? (0.310 kgm^2)
2. A flywheel with a moment of inertia of 0.859 kg m^2 accelerates at 13.0 rad/s/s. What is the torque? (11.2 mN)
3. A motor with 43.0 mN of torque accelerates at 153 rad/s/s. What is its moment of inertia? (0.281 kgm^2)
4. A torque of 21.0 mN acts on a motor with a moment of inertia of 1.53 kg m^2. What is the angular acceleration? (13.7 rad/s/s)
5. What torque will accelerate a motor with a moment of inertia of 3.87 kg m^2 at 6.60 rad/s/s? (25.5 mN)

F = ma problems, but $I = \frac{1}{2} mr^2$ (cylinder), $\frac{2}{5}mr^2$ (sphere), or kinematics, or $\Gamma = rF$

6. A 0.400 m <u>diameter</u>, 4.30 kg sphere accelerates about its center at 6.80 rad/s/s. What is the torque? (0.468 mN)
7. A drill with a moment of inertia of 0.0180 kg m^2 is slowed by a frictional torque of 0.270 mN. If it is moving at 142 rad/s, how many radians will it go through before it stops? (672 rad)
8. A grinding wheel with a <u>diameter</u> of 0.640 m and a moment of inertia of 0.172 kg m^2 decelerates at -8.90 rad/s/s because of a tangential friction force applied at the edge. What is this force? (4.78 N)
9. A torque of 19.0 mN acts on a flywheel with a moment of inertia of 3.20 kg m^2. If it starts at rest, in what time will it go through 16.0 radians? (2.32 s)
10. A torque of 3.50 mN acts on a 7.10 kg, 0.132 m <u>diameter</u> shot put. (a sphere) What is the angular acceleration of the sphere? (283 rad/s/s)

Same as above with unit conversions:

11. A 0.219 m <u>diameter</u> bowling ball has a tangential force 5.50 N acting on it and it accelerates from rest going through 13.0 rotations in 3.21 seconds. What is the moment of inertia of the ball? (0.0380 kgm^2)
12. A 0.310 m radius flywheel (essentially a thin ring) with a mass of 3.20 kg. What is its rate of deceleration if you exert a force of 2.20 N tangentially at its edge? (2.22 rad/s/s)
13. A flywheel is a 13.2 kg 1.80 m <u>diameter</u> thin ring. If you exert a force of 51.0 N tangentially at its edge, what is its angular acceleration? (4.29 rad/s/s)
14. A flywheel that is a 0.730 m <u>diameter</u> thin ring with a mass of 16.0 kg would require what torque to accelerate from rest to 1120 RPM in 8.10 seconds? (30.9 mN)
15. What is the moment of inertia of a 0.258 m radius flywheel if when you exert a tangential force of 11.5 N at the edge it accelerates from rest to 680. RPMs in 123 rotations? (0.904 kgm^2)

Same as above with unit conversions and kinematics:

16. A 161 kg 4.72 m <u>diameter</u> (cylindrical) merry go round is sped up from rest by a 25.0 N force applied tangentially at its edge. What is its speed in RPMs after 38.0 seconds? (47.8 RPM)
17. A 2.10 m radius, 351 kg (cylindrical) merry go round spinning at 75.0 RPM slows to a halt in 11.5 rotations. What force applied tangentially at the edge would cause this? (157 N)
18. A 232 kg 4.10 m <u>diameter</u> (cylindrical) Merry go round is stopped from a speed of 94.0 RPM in 55.0 seconds. What frictional force applied tangentially at the edge would cause this? (42.6 N)
19. A 243 kg 1.70 m radius (cylindrical) merry go round stops from a speed of 68.0 RPM because of a frictional force applied at the edge of 8.50 N. How many rotations does it go through in stopping? (98.1 rotations)
20. A 4.60 m <u>diameter</u> (cylindrical) merry go round speeds up from rest going through 5.10 rotations in 41.0 seconds because of a 15.0 N force applied tangentially at the edge. What is the mass of the merry go round? (342 kg)

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I (about centers): cylinder = $^1/_2mr^2$, ring/point = mr^2, sphere = $^2/_5mr^2$, rod = $^1/_{12}mL^2$ (= $^1/_3mL^2$ about end)

1-3: A 12.0 g, 0.0140 m radius marble rolls down an incline that is 3.80 m long, and loses 0.120 m of elevation.

1. Set up the appropriate dynamics or conservation of energy equation, substitute for ω or α, and for I, and solve for v or a. Show your steps below. Give an exact answer. $a = \frac{5}{7} g \bullet \sin(\theta)$ $v = \sqrt{\frac{10}{7} gh}$

2. Solve for the final velocity of the marble at the bottom of the incline.

3. Calculate the acceleration of the marble as it rolls down the incline.

4-5: A 45.0 kg child is 1.80 m from the center of a 2.00 m radius merry go round that is a 160. kg cylinder.

4. If the merry go round speeds up from 1.40 rad/s to 2.10 rad/s in 4.00 seconds, what torque was applied?

5. If the merry go round is spinning at 45.0 RPM and the child moves from 1.80 m from the center to 0.600 m from the center, what is the new angular velocity of the merry go round in RPMs?

Angular Energy and Momentum problems from 8.3

A Basic Energy:

1. What is the kinetic energy of a flywheel with a moment of inertia of 12.4 kgm^2 that is spinning at 17.8 rad/s? (1960 J)
2. A flywheel spins at 87.0 rot/s when it is storing 12,500 J of kinetic energy. What is its moment of inertia? (0.0837 kgm^2)
3. What is the speed in RPMs of a 4.50 kg 34.0 cm diameter cylindrical grinding disk if it has 340. J of rotational kinetic energy? (977 RPM)
4. A 4.50 kg 12.0 cm radius bowling ball is rolling at 3.20 m/s. What is its translational kinetic energy? What is its rotational kinetic energy? What is its total kinetic energy? If it rolled from rest down a hill, how high is the hill? (23.0 J, 9.22 J, 32.3 J 0.731 m)
5. If linear work is given by $W = Fs$, then angular work is $W = \Gamma\theta$. Use energy to find the angular final velocity of a flywheel that has a moment of inertia of 8.50 kgm^2 after it has been sped from rest up by a torque of 52.0 mN through 84.0 radians. (32.1 Rad/s)

B Rolling problems:

For all of these:

a. Set up the appropriate <u>dynamics</u> or <u>conservation of energy</u> equation, substitute for <u>ω or α</u>, and for <u>I</u>, and solve for <u>v or a</u>. Show your steps Give an exact answer. (you will need to give an answer with a simplified fraction!)
b. Solve for the final velocity of the marble at the bottom of the incline.
c. Calculate the acceleration of the marble as it rolls down the incline.

1. A 11.0 g, 0.0110 m radius unique circular solid with a moment of inertia given by $^2/_5mr^2$, rolls down an incline that is 2.60 m long, and loses 0.560 m of elevation. (2.80 m/s, 1.51 m/s/s)
2. A 13.0 g, 0.0130 m radius unique circular solid with a moment of inertia given by $^1/_2mr^2$, rolls down an incline that is 5.10 m long, and loses 1.90 m of elevation. (4.99 m/s, 2.44 m/s/s)
3. A 15.0 g, 0.0140 m radius unique circular solid with a moment of inertia given by $^1/_3mr^2$, rolls down an incline that is 4.10 m long, and loses 1.30 m of elevation. (4.37 m/s, 2.33 m/s/s)
4. A 143.0 g, 0.0450 m radius unique circular solid with a moment of inertia given by $^2/_7mr^2$, rolls down an incline that is 3.30 m long, and loses 1.10 m of elevation. (4.10 m/s, 2.54 m/s/s)
5. A 12.0 g, 0.0120 m radius unique circular solid with a moment of inertia given by $^7/_8mr^2$, rolls down an incline that is 3.20 m long, and loses 0.340 m of elevation. (1.89 m/s, 0.556 m/s/s)

C Basic Momentum:

1. What is the angular momentum of a disk with a moment of inertia of 0.145 kgm^2 that is spinning at 45.0 rad/s? (6.53 kgm^2/s)
2. What angular velocity in rad/s must a 120. kg 1.80 m radius cylindrical merry go round go to have 2360 kg m^2/s of angular momentum? (12.1 rad/s)
3. What torque would speed up a merry go round with 296 kgm^2 of rotational inertia from rest to 6.28 rad/s in 32.0 seconds? (58.1 mN)
4. A 2.60 kg cylindrical flywheel with a diameter of 54.0 cm is spinning at 115 rad/s. If a frictional torque of 1.30 mN acts on it, in what time would it stop? (8.38 s)
5. A ballerina spinning at 1.20 rev/sec with a moment of inertia of 2.60 Kg m^2 pulls her arms in so that her new moment of inertia is 1.80 Kg m^2. What is her new angular speed? (1.73 rev/sec)
6. A group of children playing on a merry go round spinning at 52.0 rpm with a moment of inertia of 200. Kg m^2 move to its center so that the new angular velocity is 86.7 RPM. What is the new moment of inertia? (120. kgm^2)

D Momentum Questions:

1. A 54.0 kg child is 1.80 m from the center of a 2.10 m radius merry go round that is a 170. kg cylinder.
a. If a torque of 92.0 mN is applied for 13.0 seconds, what is the change in angular velocity? b. The child moves out to a distance of 2.10 m, and as a result the merry go round is spinning at 0.450 rot/s. What was its initial angular velocity in rot/s? (2.18 rad/s, 0.502 rot/s)

2. A 68.0 kg child is 2.70 m from the center of a 3.30 m radius merry go round that is a 140. kg cylinder.
a. For what time must a torque of 31.0 mN act to accelerate the merry go round from rest to 5.20 rad/s? b. When the merry go round is spinning at 21.0 RPM, the child moves in to a distance of 1.90 m from the center. What is the final angular velocity in RPM? (211 s, 26.2 RPM)

3. A 51.0 kg child is 1.10 m from the center of a 2.40 m radius merry go round that is a 160. kg cylinder.
a. If the merry go round speeds up from rest to 4.70 rad/s in 14.0 seconds, what torque was acting? b. When the merry go round is rotating at 0.970 rot/s, the child moves out to a distance of 2.30 m from the center. What is the new angular velocity of the merry go round in rot/s? (175 mN, 0.694 rot/s)

4. A 41.0 kg child is 2.20 m from the center of a 2.40 m radius merry go round that is a 150. kg cylinder.
a. If a torque of 95.0 mN acts on the merry go round for 8.00 seconds, what is the change in angular velocity? b. The child moves in to a distance of 1.10 m from the center, and as a result, the angular velocity of the merry go round is 65.0 RPM. What was the initial angular velocity in RPM? (1.21 rad/s, 49.7 RPM)

5. A 58.0 kg child is 1.00 m from the center of a 2.20 m radius merry go round that is a 180. kg cylinder.
a. For what time must a torque of 35.0 mN act on the merry go round to change its angular velocity from rest to 3.50 rad/s? b. If the merry go round is spinning at 0.780 rot/s, and the child moves out to 2.20 m from the center, what is the final angular velocity in rot/s? (49.4 s, 0.537 rot/s)

So you think you're so dang smart?

Giancoli #67: Suppose a 55-kg person stands at the edge of a 6.5-m diameter merry-go-round turntable that is mounted on frictionless bearings and has a moment of inertia of 1700 kgm^2. The turntable is at rest initially, but when the person begins running at a speed of 3.8 m/s (with respect to the turntable) around its edge, the turntable begins to rotate in the opposite direction. Calculate the angular velocity of the turntable.
(-0.30 rad/s)

Gyroscope Investigation

1. You will need a gyroscope, a gear puller, a gyroscope stand, and a love for rotational mechanics.
2. Get the gyroscope spinning by using the gear puller. Hold the gyroscope firmly, and pull the handle - being careful not to strip the little teeth. Play with it over a table. If it drops on the floor it will break. Come up with a stupid gyroscope trick.
3. Get the gyroscope spinning anti-clockwise as seen from above (This way the L vector is pointing up), put the bottom of the gyro into stand Note carefully which way the gyroscope precesses.
4. **Draw careful diagrams** that a) show the direction of the torque on the gyroscope (Due to gravity) the axis about which this torque acts is the stand $\Gamma = r \times F$, so r is away from the stand, F is straight down, b) show the direction of the angular momentum vector, c) show that the direction of precession has the tip of the L vector going in the direction of the torque.
5. Answer these questions:
   - A. Measure the mass of the rotor by weighing the gyroscope, and subtracting the 23.5 grams that is the cage. Measure the radius of the rotor, and use a formula like $I = mr^2$ (or is it $.9mr^2$? – feel free to make your own formula) to **find the moment of inertia of the rotor in $\mathbf{kgm^2}$**.
   - B. The axle has a diameter of 3.9 mm (0.0039 m). Supposing the puller was moving about 1.5 m/s at the end of your pull,
     1. **calculate the angular velocity of the gyro**, (use $v = \omega r$) and
     2. **calculate the angular momentum of the gyro**. ($L = I\omega$)
   - C. Calculate the **angular momentum of the earth** ($L = I\omega$). (use the interwebs to find the mass, radius, and period of rotation. Assume the earth is a sphere ($^2/_5 mr^2$). $\omega = 2\pi/T$. You can also just go to wolfram alpha and type "angular velocity of the earth") Show that it is about 7×10^{33} kgm^2/s (be a bit more exact)
6. Leave your gyroscope exactly the way you found it.

Here's what you turn in:
1. The diagram as explained in part 4.
2. The answers for part 5.