8A   SPRING 2000

MOMENTS OF INERTIA

Hoop about cylinder axis

$$I = MR^2$$

(a)

Annular cylinder (or ring) about cylinder axis

$$I = \frac{M}{2}(R_1^2 + R_2^2)$$

(b)

Solid cylinder (or disk) about cylinder axis

$$I = \frac{MR^2}{2}$$

(c)

Solid cylinder (or disk) about central diameter

$$I = \frac{MR^2}{4} + \frac{ML^2}{12}$$

(d)

Thin rod about axis through center ⊥ to length

$$I = \frac{ML^2}{12}$$

(e)

Thin rod about axis through one end ⊥ to length

$$I = \frac{ML^2}{3}$$

(f)

Solid sphere about any diameter

$$I = \frac{2MR^2}{5}$$

(g)

Thin spherical shell about any diameter

$$I = \frac{2MR^2}{3}$$

(h)

Hoop about any diameter

$$I = \frac{MR^2}{2}$$

(i)

Rectangular plate about ⊥ axis through center

$$I = \frac{M(a^2 + b^2)}{12}$$

(j)

1

8A SP 2000 FINAL   ①

(10) (1) A sinusoidal transverse water wave has a wave-length of 6 meters and a frequency of 0.3 Hz. The wave moves in the $(-z)$ direction and the displacement is along the $(\pm y)$ axis. The displacement at $z = 0.9$ m. is (-0.1) m. when the time $t = 1.2$ sec. (a) Calculate the amplitude of the wave; (b) Calculate the velocity of the wave; (c) Show explicitly that your units in part (a) are correct. $[a = 6 \text{ points}, b = c = 2 \text{ each}]$

8A SP 2000 FINAL   ②

(10)(2) Suppose that $2 \times 10^{-4} \ m^3$ of hot water at 368 K is poured into an insulated glass cup (filling it), of mass 0.3 kg, which is initially at 298 K. Assuming that no heat flows into the surroundings, calculate the final equilibrium temperature of (cup + water). <u>Specific heats</u>: glass, 840 $J \ kg^{-1} K^{-1}$; water, 4186 $J \ kg^{-1} K^{-1}$; <u>Densities</u>: water, 1000 $kg \ m^{-3}$; glass, 2000 $kg \ m^{-3}$.

8A SP2000 FINAL   ③

(15)(3) A "dumb-bell", at rest, is composed of two point masses m_1 and m_2 attached to the two ends of a massless rod of length (2r). The dumb-bell lies on a frictionless horizontal surface and can rotate about a fixed axis (normal to the surface) through point 0, as shown.

A third mass m_3 moves (normal to the axis of the dumb-bell) on the surface with velocity $\underline{v}$, hits m_2 and sticks to m_2. The dumb-bell begins to rotate. Calculate, using the conservation of angular momentum, the angular speed ω of the rotating dumb-bell just after it is hit by m_3. (Your answer will be in terms of v, r, and the masses.)

8A SP 2000 FINAL   ④

(15)(4) A spherical bubble of air rises from the bottom of a lake 10 meters deep. The volume of the bubble is 10^{-6} m³ at the lake bottom and increases as the bubble rises. Calculate the volume of the bubble at the surface of the lake. You may assume that the water temperature is constant, and that the air in the bubble behaves as an ideal gas. The atmospheric pressure above the lake is 10^5 Pa and the mass density of water is 10^3 kg m⁻³.

8A SP2000 FINAL   ⑤

(15)(5) A vertical spring is suspended at one end and a mass of 0.30 kg is attached to the other end. The spring stretches by 0.15 meter when the mass is attached. The spring is then stretched (vertically downward) an additional 0.10 meter and released from rest. (a) Calculate the value of the spring (force) constant k; (b) Calculate the angular frequency ω of oscillation; (c) Calculate the amplitude A of the oscillations; (d) Calculate the period T of the oscillations. [$a = 4, b = 4, c = 3, d = 4$ points]

8A SP 2000 FINAL   ⑥

(15)(6) Two blocks of masses m_1 and m_2 are arranged as shown. The cord is massless and the pulley is frictionless and massless. However, there *is* friction between block m_1 and the surface of the incline. (Block m_2 hangs freely vertically from the cord.) If block m_1 is just on the verge of moving up the incline, calculate the coefficient of static friction μ_s between block m_1 and the surface of the incline.
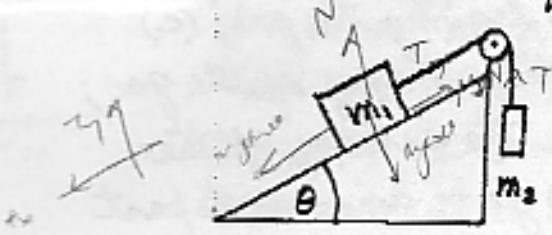
(10)(7) One mole of an ideal gas at a temperature of 300 K is compressed isothermally and reversibly from a volume of 1.0 m^3 to a volume of 0.2 m^3. (a) Calculate the change ΔE_{int} in the internal energy of the gas; (b) Calculate the amount of heat Q leaving the gas; (c) Calculate the change ΔS_{gas} in the entropy of the gas; (d) Calculate the change ΔS_{surr} in the entropy of the surroundings of the gas; (e) Does your answer to part (c) conflict with the Second Law of Thermodynamics? Justify your answer with an explanation. [Each part = 2 pts]

8A FINAL SP 2000   ⑧

(25)(8) One mole of He (a monatomic gas) is at a temperature of 120 K, with a volume of 0.1 m^3 and at a pressure of 10^4 Nm^{-2}. The gas undergoes the following three-step process. Step A is a reversible compression to a volume of 0.05 m^3 at a constant pressure of 10^4 Nm^{-2}. Step B is heating the gas at a constant volume of 0.05 m^3 to a pressure of 2×10^4 Nm^{-2}. Step C is a reversible isothermal expansion to a volume of 0.1 m^3. The gas may be assumed to be ideal at all times. (a) Calculate the temperature of the gas at the end of each step of the process; (b) Draw a pV diagram showing each step of the process, indicating on the diagram the temperatures obtained in part (a); (c) Calculate the total work done by the gas in the three-step process [a = 10, b = 5, c = 10 points].

(20)(9) A thin rod of length L and mass m stands vertically on a horizontal surface. The rod begins to fall from rest, but its lower end does not slide and acts as a pivot. Calculate the angular speed ω of the rod as a function of the angle ϕ the rod makes with the horizontal surface.

8A FINAL SP 2000   (10)

(20)(10) Two blocks of masses m_1 and m_2 slide down an inclined plane which makes an angle θ with the horizontal. The coefficients of kinetic (sliding) friction of the blocks with the surface of the incline are μ_1 and μ_2, respectively. The blocks remain in contact with each other as they slide. Calculate the accelerations a_1 and a_2 of the blocks.
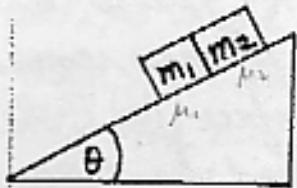
8A FINAL SP 2000   (11)

(25) (11) A small body of mass m starts from rest at the top of a hemispherical bowl of radius R, as shown. The body slides down the frictionless inner surface of the bowl, always remaining in contact with the surface. (a) If the position of the body is specified by the angular coordinate θ (as shown), calculate the angular acceleration α (relative to an axis through point O) as a function of θ; (b) Make a graph (a neat sketch will do) showing the variation of α with θ for values of θ between 0 and π radians; (c) Describe briefly in words the variation of angular acceleration with angular coordinate as the body moves [$a = 10, b = 10, c = 5$].

8A FINAL SP 2000   (12)

(20)(12) Two solid cubes of wood, each of edge l, are glued together. The cubes are of different mass densities and so have masses m_1 and m_2, where m_1 is larger than m_2. The combination of cubes is held horizontally (the cubes are side by side) in water so that it floats partially submerged. Calculate the magnitude of the net torque exerted (about an axis through the geometric center of the combination) on the combination at the instant the cubes are released.

(1)

8A (2) Final Exam Solutions - Spring 2000

(1)(a) The wave is moving in the $(-z)$ direction and the displacement is along the $(\pm y)$ axis, so the wave function is

$$y(z,t) = A \sin(kz + \omega t).$$

Since the wavelength $\lambda = 6$ m., the wave number $k = (2\pi/\lambda) = 1.047$ m^{-1}. The frequency $\nu = 0.3$ Hz, so the circular frequency $\omega = 2\pi\nu = 1.885$ Hz. We are told that the displacement y at $z = 0.9$ m., when $t = 1.2$ sec, is $y = (-0.1)$ m, so the eqn. above becomes

$$-0.1 = A \sin\left[(1.047)(0.9) + (1.885)(1.2)\right]$$

$$-0.1 = A \sin(3.204) = A(-0.0626)$$

so
$$\boxed{A = 1.596 \text{ m.}}$$ is the amplitude of the wave

(b) The velocity v of the wave is, from $v = \lambda\nu$,

$$\boxed{v = \lambda\nu = (6)(0.3) = 1.8 \text{ msec}^{-1}}$$

(c) Since λ is in meters, k is in $(meters)^{-1}$. Since z is in meters, (kz) is dimensionless. The same is true of (ωt) since ω is in sec^{-1} (Hz) and t is in seconds. The argument $(kz + \omega t)$ of the sine is therefore dimensionless, as it should be. The sine is thus a pure (that is, dimensionless) number, so the amplitude A has the same units as the displacement y, namely <u>meters</u>, which are the correct units for the amplitude.

② In this problem, we assume that the amount of heat Q (lost by water) is equal to the amount of heat Q (gained by glass) because the glass cup is insulated. Let T be the final equilibrium temperature of the (cup + water), where $368K > T > 298 K$. From the definition of specific heat C,

$$Q = m C \Delta T$$

where m is the mass and Q is the amount of heat required to raise the temperature of mass m by (ΔT) Kelvins. Then

$$Q (\text{lost by water}) = Q (\text{gained by glass})$$

$$m_W C_W (368 - T) = m_G C_G (T - 298)$$

Putting in the numerical values given for m_W, C_W, m_G, and C_G, and using

$$\text{mass} = (\text{mass density})(\text{volume}),$$

we have

$$(10^3)(2 \times 10^{-4})(4186)(368 - T) = (0.3)(840)(T - 298)$$

$$(837)(368 - T) = (252)(T - 298)$$

$$3.83 \times 10^5 = (1089)T$$

$$\boxed{T = 352 \ K}$$

(3) The conservation of angular momentum L for this system becomes

$$L \text{ (relative to } 0, \text{ before hit)} = L \text{ (relative to } 0, \text{ after hit)}$$

and

$$L \text{ (rel. } 0, \text{ before hit)} = L (m_3, \text{rel. } 0) + L \text{ (dumb-bell, rel. } 0)$$

As m_3 strikes the dumb-bell, its angular momentum (relative to 0) is $(m_3 v r)$; the initial angular momentum of the dumb-bell is zero because the dumb-bell is at rest. Therefore

$$L \text{ (rel. } 0, \text{ before hit)} = m_3 v r + 0 = m_3 v r$$

After the collision the system rotates about 0 with angular speed ω, so

$$L \text{ (rel. } 0, \text{ after hit)} = I \omega$$

where I is the moment of inertia of the dumb-bell with mass m_3 attached to m_2. From the definition of I,

$$I = m_1 r^2 + (m_2 + m_3) r^2 = (m_1 + m_2 + m_3) r^2$$

Conservation of angular momentum gives

$$m_3 v r = (m_1 + m_2 + m_3) r^2 \omega$$

$$\boxed{\omega = \frac{m_3 v}{(m_1 + m_2 + m_3) r}}$$

for the angular speed ω of the system after collision.

8A FINAL EXAM SOLUTIONS — SP 2000   (4)

(4) From Pascal's Law,

$$p(y) = p_0 + \rho g y$$

is the hydrostatic pressure at a depth y in a fluid of mass density ρ over a free surface at which the pressure is p_0. Because the bubble is stable, the air pressure inside the bubble equals the fluid pressure outside. At the surface $(y=0)$, the pressure $p(0) = p_0$, the atmospheric pressure, where $p_0 = 10^5 \, N \, m^{-2}$. At a depth $y = 10$ meters, the fluid pressure is

$$p(10) = p_0 + \rho g y = 10^5 + (10^3)(9.8)(10) = 1.98 \times 10^5 \, N \, m^{-2}.$$

Since the gas (air) in the bubble is ideal, we have

$$pV = nRT;$$

since $n, R,$ and T are all constants, (nRT) is constant, so

$$p(0) V(0) = p(10) V(10)$$

meaning that the product (pV) has the same value at the surface $(y=0)$ and at the depth $y = 10$ meters. We are given that $V(10) = 10^{-6} \, m^3$, so the volume $V(0)$ at the surface is

$$V(0) = [p(10) V(10)]/p(0) = \frac{(1.98 \times 10^5)(10^{-6})}{10^5}$$

$$\boxed{V(0) = 1.98 \times 10^{-6} \, m^3}$$ is the volume of the bubble at the surface of the lake

8A FINAL EXAM SOLUTIONS – SP 2000   ⑤

(5) With the spring stretched, the upward restoring force exerted on the mass is equal to the downward gravitational force (weight) on the mass. Then (a)

$$kx = mg.$$

$$k = (mg/x)$$

Since $m = 0.30 \, kg$, $g = 9.8 \, m\,sec^{-2}$, and $x = 0.15$ meter

$$\boxed{k = 19.6 \; N\,m^{-1}}$$

(b) The angular frequency ω of oscillation (after the mass is released from rest) is

$$\omega = (k/m)^{1/2} = [(19.6)/(0.30)]^{1/2} = 8.08 \, sec^{-1}$$

$$\boxed{\omega = 8.08 \; Hz}$$

(c) Since the spring is stretched by a further 0.1 meter and then the mass is released, the amplitude $A = 0.1$ meter:

$$\boxed{A = 0.1 \; meter}$$

(d) The period T of the oscillations is given by

$$T = (2\pi/\omega) = (6.28)/(8.08)$$

$$\boxed{T = 0.78 \; sec}$$

8A FINAL EXAM SOLUTIONS — SP 2000   (6)

(6)
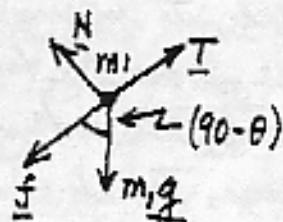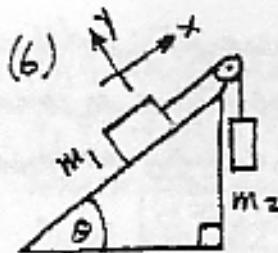
(components of $m_1 g$)
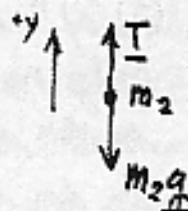
$\underline{T}$ = tension in massless cord ; $\underline{N}$ = normal force exerted on m_1
$\underline{f}$ = frictional force exerted on m_1
and where ($N = m_1 g \cos\theta$) because m_1 has zero acceleration along y.

<u>Newton's Second Law for M_1</u>: $-m_1 g \sin\theta + T - f = 0$ (m_1 at rest)
<u>Newton's Second Law for M_2</u>: $T - m_2 g = 0$ (m_2 at rest)

Since m_1 is just <u>on verge</u> of moving : $f = \mu_s N = \mu_s m_1 g \cos\theta$

so Second Law equations become
$-\sin\theta (m_1 g) + T - \mu_s m_1 g \cos\theta = 0$
$$T = m_2 g$$

and
$-\sin\theta (m_1 g) + m_2 g - \mu_s m_1 g \cos\theta = 0$

$(m_2 - m_1 \sin\theta) = \mu_s m_1 \cos\theta$

$$\boxed{\mu_s = \frac{(m_2 - m_1 \sin\theta)}{(m_1 \cos\theta)}}$$ is coefficient of static friction between m_1 and incline

8A FINAL EXAM SOLUTIONS — SP 2000   (7)

(7) (a) Since the gas is ideal, its internal energy E_{int} depends only on the temperature. Since the temperature is constant in an isothermal process, the internal energy is constant in an isothermal process. Therefore $\boxed{\Delta E_{int} = 0}$.

(b) Work is done <u>on</u> the gas when the gas is compressed, so (from our sign convention), W is ~~negative~~ in this process. From the First Law, $\Delta E_{int} = Q - W = 0$ in this isothermal process. Since W is negative, $Q = W$, so Q is <u>negative</u> also, meaning that heat energy <u>leaves</u> the gas. <u>To calculate Q</u>, we calculate

$$W = \int p \, dV = \int_{1.0}^{0.2} \frac{RT}{V} \, dV = RT \ln(0.2) = (8.31)(300)\ln(0.2)$$

$$W \approx -4012 \text{ Joules} \quad so \quad \boxed{Q = -4012 \text{ J.}} \quad \begin{array}{l} so \ 4012 \text{ J. of} \\ heat \ leaves \ gas \end{array}$$

(c) The compression is <u>reversible</u>, so $dS = (1/T)dQ$ and

$$\Delta S_{gas} = \int dS = \int (1/T) dQ = (1/T)\int dQ = Q/T \quad where \ Q < 0$$

$$\Delta S_{gas} = (-4012/300) \, JK^{-1} \Rightarrow \boxed{\Delta S_{gas} = -13.37 \, JK^{-1}}$$

and the entropy S_{gas} <u>decreases</u> by $13.37 \, JK^{-1}$ in the process.

(d) The process is <u>reversible</u>, so $\Delta S \, (gas + surroundings) = 0$, and

$$\Delta S_{gas} + \Delta S_{surr} = 0 \Rightarrow \boxed{\Delta S_{surr} = +13.37 \, JK^{-1}}$$

and the entropy of the surroundings <u>increases</u> by $13.37 \, JK^{-1}$.

(e) No. The Second Law says that ΔS (system; here the gas) can be negative as long as ΔS (system + surr.) ≥ 0.

8A FINAL EXAM SOLUTIONS — SP 2000 (8)

(8)(a) Call the starting state of the gas ①, so $p_1 = 10^4 \, Nm^{-2}$, $V_1 = 0.1 \, m^3$, $T_1 = 120 \, K$. Step A takes the gas to state ②, in which $p_2 = 10^4 \, Nm^{-2}$, $V_2 = 0.05 \, m^3$, and we want to find T_2. Since the gas is ideal, $pV = RT$; since $p_1 = p_2$, we have

$$(T_1/V_1) = (T_2/V_2) \Rightarrow (120/0.1) = (T_2/0.05) \Rightarrow \boxed{T_2 = 60 \, K}$$

is the temperature at the end of Step A. Then Step B takes the gas to state ③, in which $p_3 = 2 \times 10^4 \, Nm^{-2}$, $V_3 = 0.05 \, m^3$, and we want to find T_3. Since $V_2 = V_3$, the ideal gas law gives us

$$(T_2/p_2) = (T_3/p_3) \Rightarrow (60/10^4) = (T_3/2 \times 10^4) \Rightarrow \boxed{T_3 = 120 \, K}$$

is the temperature at the end of Step B. Then Step C takes the gas to state ④, in which $V_4 = 0.1 \, m^3$, $T_4 = 120 \, K$, and we want to find p_4. Step C is isothermal, so $\boxed{T_3 = T_4}$ and we have

$$(p_3 V_3) = (p_4 V_4) \Rightarrow (2 \times 10^4)(0.05) = (p_4)(0.1) \Rightarrow \boxed{p_4 = 10^4 \, Nm^{-2}}$$

This result tells us that state ④ is the same as state ① : process is cyclic.

(b) Draw the pV diagram of the cyclic process :
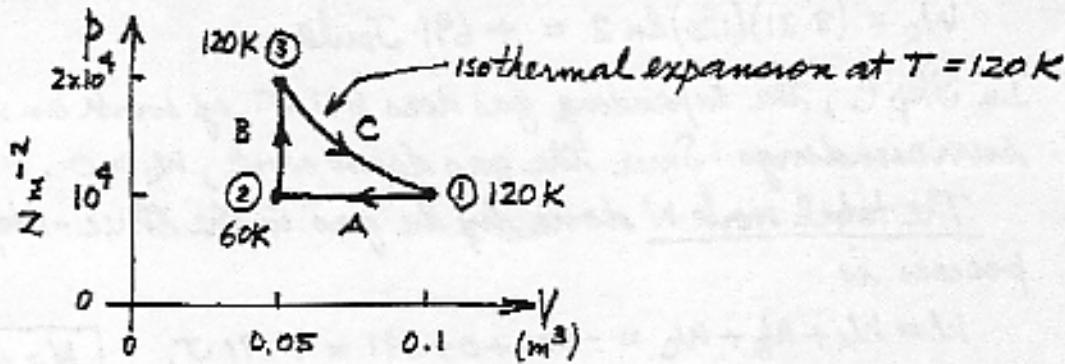
(continued →)

8A   FINAL EXAM SOLUTIONS – SP 2000   (8A)

(8) [continued] (c) To calculate the work done by the gas
we use $W = \int p \, dV$

where W is positive when the gas does work on the surrounding
and W is negative when the surroundings do work on the gas.
  In Step A, $p = const. = 10^4 \, N \, m^{-2}$, so the work W_A done
by the gas is
$$W_A = \int_1^2 p \, dV = p(V_2 - V_1) = (10^4)(0.05 - 0.10) = -500 \text{ Joules}$$

and where $W_A < 0$ because work is done on the gas in the
compression in Step A, so the work W_A done by the gas is negative.
  In Step B, the volume is constant, so no work is done
by the gas in this step:

$$W_B = 0.$$

  In Step C, the gas expands isothermally ($T = 120 K$) from
$V_3 \approx 0.05 \, m^3$ to $V_1 = 0.10 \, m^3$, so, since $pV = RT$,
$$W_C = \int_3^1 p \, dV = RT \int_3^1 \frac{dV}{V} = RT \ln\left(\frac{0.10}{0.05}\right) = RT \ln 2$$

$$W_C = (8.31)(120) \ln 2 = +691 \text{ Joules}$$

In Step C, the expanding gas does 691 J. of work on the
surroundings. Since the gas does work, $W_C > 0$.
 The total work W done by the gas in the three-step cyclic
process is
$$W = W_A + W_B + W_C = -500 + 0 + 691 = +191 \text{ J.} \quad \boxed{W = +191 \text{ J.}}$$

8A FINAL EXAM SOLUTIONS — SP 2000   ⑨

(9) The easiest solution uses conservation of energy :
the sum of kinetic and gravitational potential energy is constant as rod falls.

Rod is vertical ($\varphi = \frac{\pi}{2}$) : $U = (L/2)\, mg$, $K = 0$ (starts at rest)

Rod is falling ($\varphi < \frac{\pi}{2}$) : $\begin{cases} U = (L/2)\, mg \, \sin\varphi \\ K = \frac{1}{2} I \omega^2 = \frac{1}{2}\left(\frac{1}{3} m L^2\right)\omega^2 \end{cases}$

Conservation :

$$\frac{1}{2} mgL = \frac{1}{2} mgL \sin\varphi + \frac{1}{2}\left(\frac{1}{3} m L^2\right)\omega^2$$

$$mgL(1 - \sin\varphi) = \frac{1}{3} m L^2 \omega^2$$

$$(3g/L)(1 - \sin\varphi) = \omega^2$$

$$\boxed{\omega = (3g/L)^{1/2}(1 - \sin\varphi)^{1/2}}$$ gives angular speed ω as function of angle φ

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8A FINAL EXAM SOLUTIONS - SP 2000　(10)

(10) The situation is as shown; force diagrams are for m_1 and M_2

$$N_1 = m_1 g \cos\theta$$
$$f_1 = \mu_1 m_1 g \cos\theta$$
$$m_1 g \cos\theta$$
$$m_1 g \sin\theta$$

Block m_1

$$N_2$$
$$F' \quad f_2 = \mu_2 m_2 g \cos\theta$$
$$m_2 g \cos\theta = N_2$$
$$m_2 g \sin\theta$$
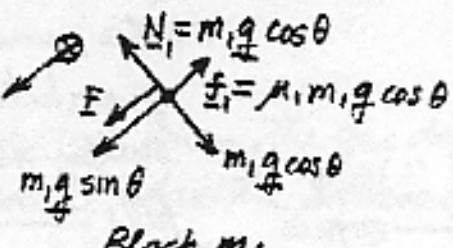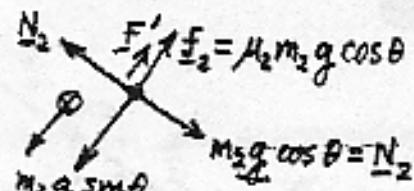
Block M_2

Force F is force exerted on m_1 by m_2 (since m_1 and m_2 are in contact). Force F' is force exerted on m_2 by m_1. Let a_1 and a_2 be magnitudes of accelerations of two masses. Then

Newton's Second Law for m_1: $F + m_1 g \sin\theta - \mu_1 m_1 g \cos\theta = m_1 a_1$

Newton's Second Law for m_2: $-F' + m_2 g \sin\theta - \mu_2 m_2 g \cos\theta = m_2 a_2$

Newton's Third Law: $\qquad\qquad\qquad\qquad F = F'$

Since blocks remain in contact with each other: $\quad a_1 = a_2$

giving four equations in the four unknowns: a_1, a_2, F, F'
Solving gives:

$$(m_1 + m_2) g \sin\theta - (\mu_1 m_1 + \mu_2 m_2) g \cos\theta = (m_1 + m_2) a_1$$

so

$$\boxed{a_1 = g \sin\theta - g \cos\theta \left(\frac{\mu_1 m_1 + \mu_2 m_2}{m_1 + m_2} \right)}$$

is acceleration (down incline) of block m_1. Acceleration a_2 of block m_2 has (since $a_1 = a_2$) same value.

8A FINAL EXAM SOLUTIONS　SP 2000　　(11)

(11)
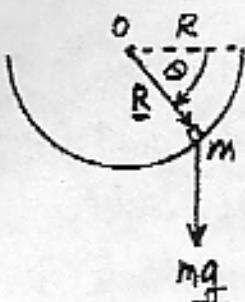
(a) We want to find the angular acceleration α as a function of the angular coordinate θ. Since the net torque $\underline{\tau}$ is related to $\underline{\alpha}$ by

$$\underline{\tau} = I\underline{\alpha}$$

we can find α if we find τ. Then

$$\underline{\tau} = \underline{r} \times \underline{F}$$
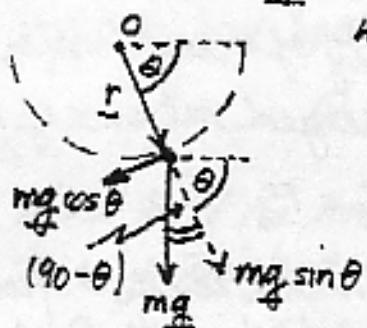
where $\underline{r}$ is radial and $|\underline{r}| = R$ and $\underline{F}$ is tangential; $|\underline{F}| = mg\cos\theta$. Since the angle between $\underline{r}$ and $\underline{F}$ is $90°$,

$$\tau = |\underline{\tau}| = rF = mgR\cos\theta$$

(The component ($mg\sin\theta$) of $m\underline{g}$ is equal to the normal force $\underline{N}$ (not shown above) in magnitude and opposite in direction.). Since $I = mR^2$, we have

$$(mR^2)\,\alpha = mgR\cos\theta \implies \boxed{\alpha = (g/R)\cos\theta} \quad \begin{array}{l}\text{gives } \alpha \\ \text{as a}\\ \text{function}\\ \text{of angle } \theta\end{array}$$

(b)

$\omega(\theta) = \frac{g}{R}\sin\theta$
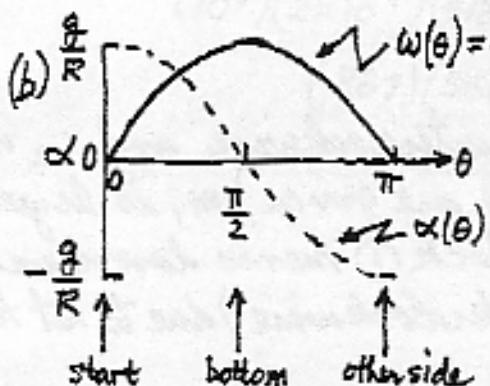
(c) At the start ($\theta = 0$), the angular acceleration $\alpha = (g/R)$ and is positive, meaning that the angular speed increases with increasing angle θ. When $\theta = \frac{\pi}{2}$, $\alpha = 0$, and the angular speed is instantaneously constant with θ. As θ increases beyond ($\pi/2$), α becomes negative and the angular speed decreases with increasing θ: $\omega(\theta) = (g/R)\sin\theta$.

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(12)
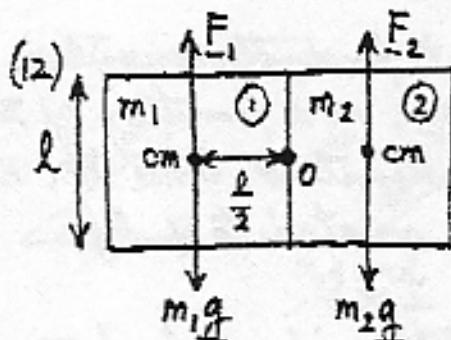
F_1 = upward buoyant force on block ①

F_2 = upward buoyant force on block ②

$m_1 g$ = weight of block ①

$m_2 g$ = weight of block ②

0 = geometric center

ρ = density of fluid (water)

$V_1 = V_2 = V$ = submerged volume of blocks (initially)

From Archimedes' Principle: $F_1 = F_2 = \rho g V$

τ_1 = torque exerted by forces on ① about center 0 of combination

τ_2 = torque exerted by forces on ② about center 0 of combination

$$\tau_1 = (\rho g V - m_1 g)\left(\frac{\ell}{2}\right) \;;\; \tau_2 = (\rho g V - m_2 g)\left(\frac{\ell}{2}\right)$$

where (since $m_1 \neq m_2$) torques τ_1 and τ_2 are in opposite directions, so the net torque is

$$\tau = (\tau_2 - \tau_1) = \rho g V \frac{\ell}{2} - m_2 g \frac{\ell}{2} - \rho g V \frac{\ell}{2} + m_1 g \frac{\ell}{2}$$

$$\boxed{\tau = (m_1 - m_2) g \frac{\ell}{2}}$$

Since τ_1 moves blocks counterclockwise and τ_2 moves blocks clockwise, and (we are given) m_1 is larger than m_2, $\tau > 0$, meaning block ① moves downward (the combination moves counterclockwise) due to net torque τ.