



AP[®] Physics C: Mechanics 2003 Free-Response Questions

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TABLE OF INFORMATION FOR 2003

CONSTANTS AND CONVERSION FACTORS		UNITS		PREFIXES			
		Name	Symbol	Factor	Prefix	Symbol	
1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$ $= 931 \text{ MeV}/c^2$	meter	m	10^9	giga	G	
Proton mass,	$m_p = 1.67 \times 10^{-27} \text{ kg}$	kilogram	kg	10^6	mega	M	
Neutron mass,	$m_n = 1.67 \times 10^{-27} \text{ kg}$	second	s	10^3	kilo	k	
Electron mass,	$m_e = 9.11 \times 10^{-31} \text{ kg}$	ampere	A	10^{-2}	centi	c	
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19} \text{ C}$	kelvin	K	10^{-3}	milli	m	
Avogadro's number,	$N_0 = 6.02 \times 10^{23} \text{ mol}^{-1}$	mole	mol	10^{-6}	micro	μ	
Universal gas constant,	$R = 8.31 \text{ J}/(\text{mol} \cdot \text{K})$	hertz	Hz	10^{-9}	nano	n	
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23} \text{ J/K}$	newton	N	10^{-12}	pico	p	
Speed of light,	$c = 3.00 \times 10^8 \text{ m/s}$	pascal	Pa	VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES			
Planck's constant,	$h = 6.63 \times 10^{-34} \text{ J} \cdot \text{s}$ $= 4.14 \times 10^{-15} \text{ eV} \cdot \text{s}$	joule	J				
	$hc = 1.99 \times 10^{-25} \text{ J} \cdot \text{m}$ $= 1.24 \times 10^3 \text{ eV} \cdot \text{nm}$	watt	W	θ	$\sin \theta$	$\cos \theta$	$\tan \theta$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2$	coulomb	C	0°	0	1	0
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$	volt	V	30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7} (\text{T} \cdot \text{m})/\text{A}$	ohm	Ω	37°	3/5	4/5	3/4
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7} (\text{T} \cdot \text{m})/\text{A}$	henry	H	45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
Universal gravitational constant,	$G = 6.67 \times 10^{-11} \text{ m}^3/\text{kg} \cdot \text{s}^2$	farad	F	53°	4/5	3/5	4/3
Acceleration due to gravity at the Earth's surface,	$g = 9.8 \text{ m/s}^2$	tesla	T	60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
1 atmosphere pressure,	1 atm = $1.0 \times 10^5 \text{ N/m}^2$ $= 1.0 \times 10^5 \text{ Pa}$	degree Celsius	$^\circ\text{C}$	90°	1	0	∞
1 electron volt,	1 eV = $1.60 \times 10^{-19} \text{ J}$	electron-volt	eV				

The following conventions are used in this examination.

- I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
- II. The direction of any electric current is the direction of flow of positive charge (conventional current).
- III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
- IV. For mechanics and thermodynamics equations, W represents the work done on a system.

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2003

MECHANICS

$v = v_0 + at$	$a =$ acceleration
$x = x_0 + v_0t + \frac{1}{2}at^2$	$F =$ force
$v^2 = v_0^2 + 2a(x - x_0)$	$f =$ frequency
$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$	$h =$ height
$\mathbf{F} = \frac{d\mathbf{p}}{dt}$	$I =$ rotational inertia
$\mathbf{J} = \int \mathbf{F} dt = \Delta\mathbf{p}$	$J =$ impulse
$\mathbf{p} = m\mathbf{v}$	$K =$ kinetic energy
$F_{fric} \leq \mu N$	$k =$ spring constant
$W = \int \mathbf{F} \cdot d\mathbf{r}$	$\ell =$ length
$K = \frac{1}{2}mv^2$	$L =$ angular momentum
$P = \frac{dW}{dt}$	$m =$ mass
$P = \mathbf{F} \cdot \mathbf{v}$	$N =$ normal force
$\Delta U_g = mgh$	$P =$ power
$a_c = \frac{v^2}{r} = \omega^2 r$	$p =$ momentum
$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$	$r =$ radius or distance
$\sum \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$	$\mathbf{r} =$ position vector
$I = \int r^2 dm = \sum mr^2$	$T =$ period
$\mathbf{r}_{cm} = \sum m\mathbf{r} / \sum m$	$t =$ time
$v = r\omega$	$U =$ potential energy
$\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$	$v =$ velocity or speed
$K = \frac{1}{2}I\omega^2$	$W =$ work done on a system
$\omega = \omega_0 + \alpha t$	$x =$ position
$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$	$\mu =$ coefficient of friction
$\mathbf{F}_s = -k\mathbf{x}$	$\theta =$ angle
$U_s = \frac{1}{2}kx^2$	$\tau =$ torque
$T = \frac{2\pi}{\omega} = \frac{1}{f}$	$\omega =$ angular speed
$T_s = 2\pi\sqrt{\frac{m}{k}}$	$\alpha =$ angular acceleration
$T_p = 2\pi\sqrt{\frac{\ell}{g}}$	
$\mathbf{F}_G = -\frac{Gm_1m_2}{r^2} \hat{\mathbf{r}}$	
$U_G = -\frac{Gm_1m_2}{r}$	

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$	$A =$ area
$\mathbf{E} = \frac{\mathbf{F}}{q}$	$B =$ magnetic field
$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$	$C =$ capacitance
$E = -\frac{dV}{dr}$	$d =$ distance
$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$	$E =$ electric field
$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$	$\mathcal{E} =$ emf
$C = \frac{Q}{V}$	$F =$ force
$C = \frac{\kappa\epsilon_0 A}{d}$	$I =$ current
$C_p = \sum_i C_i$	$L =$ inductance
$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$	$\ell =$ length
$I = \frac{dQ}{dt}$	$n =$ number of loops of wire per unit length
$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$	$P =$ power
$R = \frac{\rho\ell}{A}$	$Q =$ charge
$V = IR$	$q =$ point charge
$R_s = \sum_i R_i$	$R =$ resistance
$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$	$r =$ distance
$P = IV$	$t =$ time
$\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$	$U =$ potential or stored energy
$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I$	$V =$ electric potential
$\mathbf{F} = \int I d\boldsymbol{\ell} \times \mathbf{B}$	$v =$ velocity or speed
$B_s = \mu_0 nI$	$\rho =$ resistivity
$\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$	$\phi_m =$ magnetic flux
$\mathcal{E} = -\frac{d\phi_m}{dt}$	$\kappa =$ dielectric constant
$\mathcal{E} = -L \frac{dI}{dt}$	
$U_L = \frac{1}{2}LI^2$	

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2003

GEOMETRY AND TRIGONOMETRY

Rectangle

$$A = bh$$

Triangle

$$A = \frac{1}{2}bh$$

Circle

$$A = \pi r^2$$

$$C = 2\pi r$$

Parallelepiped

$$V = \ell wh$$

Cylinder

$$V = \pi r^2 \ell$$

$$S = 2\pi r \ell + 2\pi r^2$$

Sphere

$$V = \frac{4}{3} \pi r^3$$

$$S = 4\pi r^2$$

Right Triangle

$$a^2 + b^2 = c^2$$

$$\sin \theta = \frac{a}{c}$$

$$\cos \theta = \frac{b}{c}$$

$$\tan \theta = \frac{a}{b}$$

A = area

C = circumference

V = volume

S = surface area

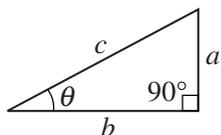
b = base

h = height

ℓ = length

w = width

r = radius



CALCULUS

$$\frac{df}{dx} = \frac{df}{du} \frac{du}{dx}$$

$$\frac{d}{dx} (x^n) = nx^{n-1}$$

$$\frac{d}{dx} (e^x) = e^x$$

$$\frac{d}{dx} (\ln x) = \frac{1}{x}$$

$$\frac{d}{dx} (\sin x) = \cos x$$

$$\frac{d}{dx} (\cos x) = -\sin x$$

$$\int x^n dx = \frac{1}{n+1} x^{n+1}, \quad n \neq -1$$

$$\int e^x dx = e^x$$

$$\int \frac{dx}{x} = \ln|x|$$

$$\int \cos x dx = \sin x$$

$$\int \sin x dx = -\cos x$$

2003 AP[®] PHYSICS C: MECHANICS FREE-RESPONSE QUESTIONS

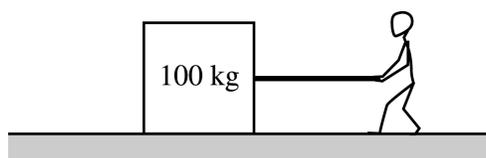
PHYSICS C

Section II, MECHANICS

Time—45 minutes

3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.



Mech. 1.

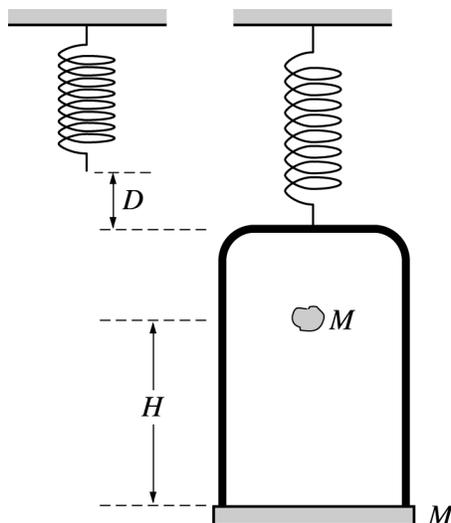
The 100 kg box shown above is being pulled along the x -axis by a student. The box slides across a rough surface, and its position x varies with time t according to the equation $x = 0.5t^3 + 2t$, where x is in meters and t is in seconds.

- (a) Determine the speed of the box at time $t = 0$.
- (b) Determine the following as functions of time t .
 - i. The kinetic energy of the box
 - ii. The net force acting on the box
 - iii. The power being delivered to the box
- (c) Calculate the net work done on the box in the interval $t = 0$ to $t = 2$ s.
- (d) Indicate below whether the work done on the box by the student in the interval $t = 0$ to $t = 2$ s would be greater than, less than, or equal to the answer in part (c).

___ Greater than ___ Less than ___ Equal to

Justify your answer.

2003 AP[®] PHYSICS C: MECHANICS FREE-RESPONSE QUESTIONS



Mech. 2.

An ideal spring is hung from the ceiling and a pan of mass M is suspended from the end of the spring, stretching it a distance D as shown above. A piece of clay, also of mass M , is then dropped from a height H onto the pan and sticks to it. Express all algebraic answers in terms of the given quantities and fundamental constants.

- Determine the speed of the clay at the instant it hits the pan.
- Determine the speed of the pan just after the clay strikes it.
- Determine the period of the simple harmonic motion that ensues.
- Determine the distance the spring is stretched (from its initial unstretched length) at the moment the speed of the pan is a maximum. Justify your answer.
- The clay is now removed from the pan and the pan is returned to equilibrium at the end of the spring. A rubber ball, also of mass M , is dropped from the same height H onto the pan, and after the collision is caught in midair before hitting anything else.

Indicate below whether the period of the resulting simple harmonic motion of the pan is greater than, less than, or the same as it was in part (c).

_____ Greater than _____ Less than _____ The same as

Justify your answer.

2003 AP[®] PHYSICS C: MECHANICS FREE-RESPONSE QUESTIONS

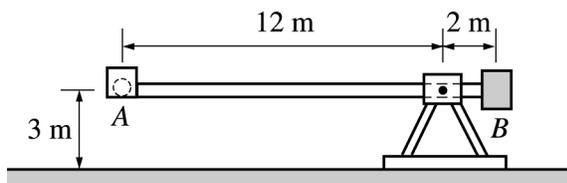


Figure 1

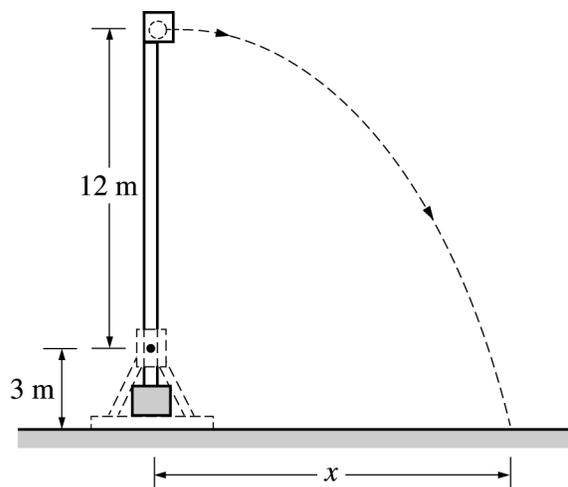


Figure 2

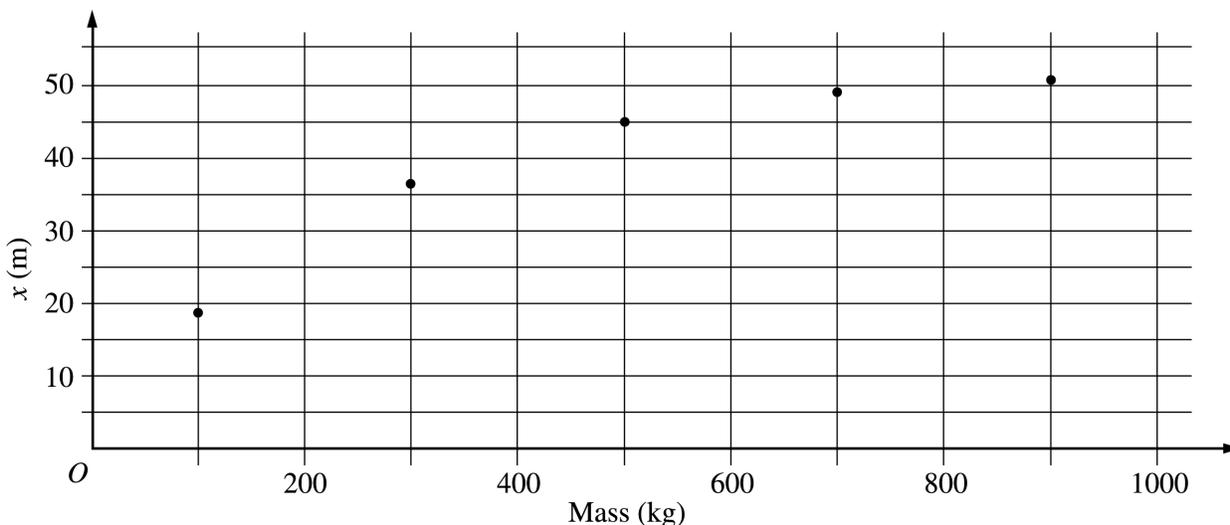
Mech. 3.

Some physics students build a catapult, as shown above. The supporting platform is fixed firmly to the ground. The projectile, of mass 10 kg, is placed in cup *A* at one end of the rotating arm. A counterweight bucket *B* that is to be loaded with various masses greater than 10 kg is located at the other end of the arm. The arm is released from the horizontal position, shown in Figure 1, and begins rotating. There is a mechanism (not shown) that stops the arm in the vertical position, allowing the projectile to be launched with a horizontal velocity as shown in Figure 2.

- (a) The students load five different masses in the counterweight bucket, release the catapult, and measure the resulting distance x traveled by the 10 kg projectile, recording the following data.

Mass (kg)	100	300	500	700	900
x (m)	18	37	45	48	51

- i. The data are plotted on the axes below. Sketch a best-fit curve for these data points.



- ii. Using your best-fit curve, determine the distance x traveled by the projectile if 250 kg is placed in the counterweight bucket.

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GO ON TO THE NEXT PAGE.

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- (b) The students assume that the mass of the rotating arm, the cup, and the counterweight bucket can be neglected. With this assumption, they develop a theoretical model for x as a function of the counterweight mass using the relationship $x = v_x t$, where v_x is the horizontal velocity of the projectile as it leaves the cup and t is the time after launch.
- How many seconds after leaving the cup will the projectile strike the ground?
 - Derive the equation that describes the gravitational potential energy of the system relative to the ground when in the position shown in Figure 1, assuming the mass in the counterweight bucket is M .
 - Derive the equation for the velocity of the projectile as it leaves the cup, as shown in Figure 2.
- (c)
- Complete the theoretical model by writing the relationship for x as a function of the counterweight mass using the results from (b)i and (b)iii.
 - Compare the experimental and theoretical values of x for a counterweight bucket mass of 300 kg. Offer a reason for any difference.

END OF SECTION II, MECHANICS