AP® Physics B
2012 Free-Response Questions

About the College Board

TABLE OF INFORMATION DEVELOPED FOR 2012

CONSTANTS AND CONVERSION FACTORS

Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1 \text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg•s^2
Universal gas constant, $R = 8.31$ J/(mol•K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	

1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg} = 931 \text{ MeV}/c^2$
Planck's constant,	$h = 6.63 \times 10^{-34}$ J•s $= 4.14 \times 10^{-15}$ eV•s
	$hc = 1.99 \times 10^{-25}$ J•m $= 1.24 \times 10^{3}$ eV•nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N•m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N•m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T•m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T•m)/A
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS								
	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES

Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	$0°$	$30°$	$37°$	$45°$	$53°$	$60°$	$90°$
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam.

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.

NEWTONIAN MECHANICS

$$\upsilon = \upsilon_0 + at$$

$$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$$

$$\upsilon^2 = \upsilon_0^2 + 2a(x - x_0)$$

$$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$$

$$F_{fric} \le \mu N$$

$$a_c = \frac{\upsilon^2}{r}$$

$$\tau = rF \sin\theta$$

$$\mathbf{p} = m\mathbf{v}$$

$$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$$

$$K = \frac{1}{2}m\upsilon^2$$

$$\Delta U_g = mgh$$

$$W = F\Delta r\cos\theta$$

$$P_{avg} = \frac{W}{\Delta t}$$

$$P = F\upsilon\cos\theta$$

$$\mathbf{F}_s = -k\mathbf{x}$$

$$U_s = \frac{1}{2}kx^2$$

$$T_s = 2\pi\sqrt{\frac{m}{k}}$$

$$T_p = 2\pi\sqrt{\frac{\ell}{g}}$$

$$T = \frac{1}{f}$$

$$F_G = -\frac{Gm_1m_2}{r^2}$$

$$U_G = -\frac{Gm_1m_2}{r}$$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$$F = \frac{kq_1q_2}{r^2}$$

$$\mathbf{E} = \frac{\mathbf{F}}{q}$$

$$U_E = qV = \frac{kq_1q_2}{r}$$

$$E_{avg} = -\frac{V}{d}$$

$$V = k\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + \ldots\right)$$

$$C = \frac{Q}{V}$$

$$C = \frac{\epsilon_0 A}{d}$$

$$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$$

$$I_{avg} = \frac{\Delta Q}{\Delta t}$$

$$R = \frac{\rho\ell}{A}$$

$$V = IR$$

$$P = IV$$

$$C_p = C_1 + C_2 + C_3 + \ldots$$

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

$$R_s = R_1 + R_2 + R_3 + \ldots$$

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

$$F_B = q\upsilon B\sin\theta$$

$$F_B = BI\ell\sin\theta$$

$$B = \frac{\mu_0}{2\pi}\frac{I}{r}$$

$$\phi_m = BA\cos\theta$$

$$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$$

$$\mathcal{E} = B\ell\upsilon$$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho g h$

$F_{buoy} = \rho V g$

$A_1 \upsilon_1 = A_2 \upsilon_2$

$P + \rho g y + \frac{1}{2}\rho \upsilon^2 = \text{const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \dfrac{kA\,\Delta T}{L}$

$P = \dfrac{F}{A}$

$PV = nRT = Nk_B T$

$K_{avg} = \frac{3}{2} k_B T$

$\upsilon_{rms} = \sqrt{\dfrac{3RT}{M}} = \sqrt{\dfrac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\dfrac{W}{Q_H}\right|$

$e_c = \dfrac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
m = mass
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
υ = velocity or speed
υ_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \dfrac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$\upsilon = f\lambda$

$n = \dfrac{c}{\upsilon}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \dfrac{n_2}{n_1}$

$\dfrac{1}{s_i} + \dfrac{1}{s_0} = \dfrac{1}{f}$

$M = \dfrac{h_i}{h_0} = -\dfrac{s_i}{s_0}$

$f = \dfrac{R}{2}$

$d\sin\theta = m\lambda$

$x_m \approx \dfrac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
υ = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

Circle
$A = \pi r^2$
$C = 2\pi r$

Rectangular Solid
$V = \ell w h$

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

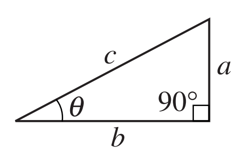
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

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

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

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

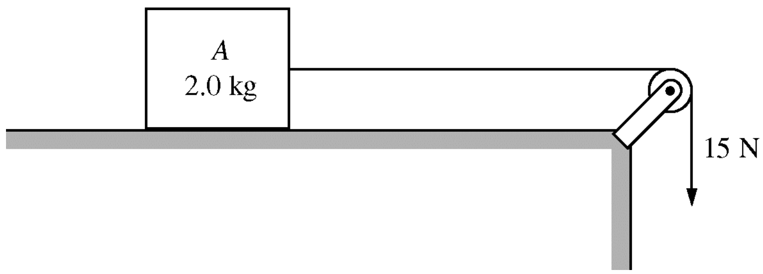
$\tan\theta = \dfrac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 11 minutes for answering each of Questions 2, 3, 4, 6, and 7 and about 17 minutes for answering each of Questions 1 and 5. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



1. (15 points)

   Block *A* of mass 2.0 kg is pulled along a horizontal table by a force of 15 N, which is applied by a light string that passes over a light frictionless pulley, as shown above. The coefficient of kinetic friction between the block and the surface is 0.25.

   (a) On the dot below, which represents the block, draw and label the forces (not components) that act on the block as it is pulled across the table.

   (b) Calculate the magnitude of the acceleration of the block.

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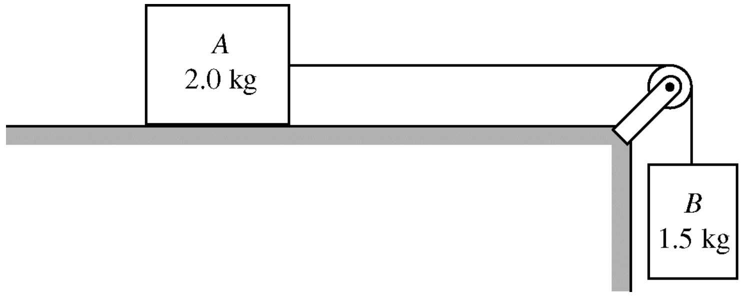


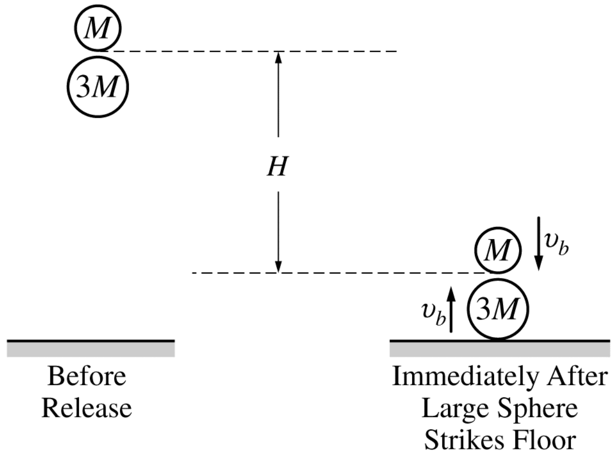
The applied force is removed. Block *B* of mass 1.5 kg is now attached to the string, as shown above. The system is released from rest so that the 1.5 kg box descends and the 2.0 kg block is again pulled across the table.

(c) Calculate the acceleration of the 1.5 kg block as it descends.

(d) Calculate the tension in the string connecting the two blocks.

(e) Calculate the distance that the 1.5 kg block descends in 0.40 s.

(f) If this system is set up in a laboratory and the acceleration of the 1.5 kg block is experimentally determined, the experimental value is found to be smaller than the value calculated above. If the given value for the coefficient of friction is correct and air resistance is negligible, explain briefly, but specifically, why the experimental value of the acceleration is smaller.



2. (10 points)

A small and a large sphere, of mass M and $3M$ respectively, are arranged as shown on the left side of the figure above. The spheres are then simultaneously dropped from rest. When the large sphere strikes the floor, the spheres have fallen a height H. Assume air resistance is negligible. Express all answers in terms of M, H, and fundamental constants, as appropriate.

(a) Derive an expression for the speed v_b with which the large sphere strikes the floor.

Immediately after striking the floor, the large sphere is moving upward with speed v_b and collides head-on with the small sphere, which is moving downward with identical speed v_b at that instant. Immediately after the collision, the small sphere moves upward with speed v_S and the large sphere has speed v_L.

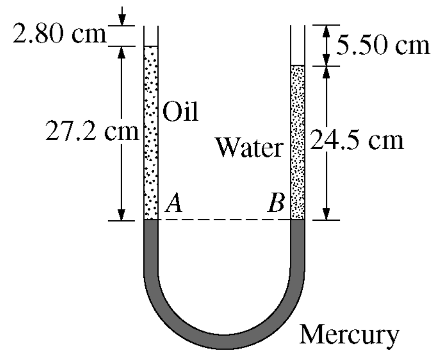
(b) Derive an equation that relates v_b, v_S, and v_L.

In this particular situation $v_L = 0$.

(c) Use your relationship from part (b) to determine the speed of the small sphere in terms of v_b.

(d) Indicate whether the collision is elastic. Justify your answer using your results from parts (b) and (c).

(e) Determine the height h that the small sphere rises above its lowest position, in terms of the original height H.

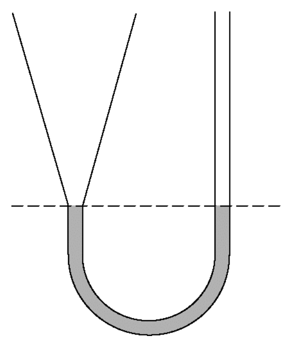


3. (10 points)

A glass U-tube with a uniform diameter of 0.850 cm is used to determine the density of an oil. As shown in the figure above, a 24.5 cm column of water balances a 27.2 cm column of the oil so that interfaces A and B of the mercury with the other liquids are at the same height. The density of water is $1.00 \times 10^3\ \text{kg/m}^3$.

(a) Calculate the density of the oil.

(b) Calculate the absolute pressure at B, the interface between the water and the mercury.



A new tube, identical to the U-tube except for a cone shape on the left, as shown above, is filled with the same volume of mercury that was in the U-tube. The mercury is at the same height on both sides of the new tube as it was in the U-tube, as shown by the dashed line. The same volumes of oil and water that were in the U-tube are now poured into the new tube, on the left and right respectively.

(c) Indicate the new position of B relative to A.

____ Above A ____ Below A ____ At the same height as A

Justify your answer.

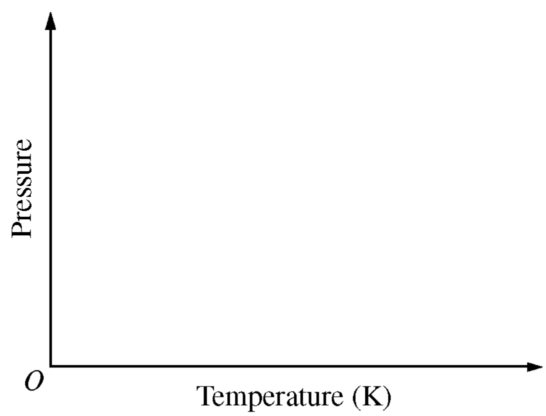
(d) A small piece of wood with density less than that of the oil is placed so that it floats in the left side of the tube. Indicate whether the pressure at the bottom of the tube increases, decreases, or remains the same.

____ Increases ____ Decreases ____ Remains the same

4. (10 points)

A cylindrical container is fitted with a frictionless piston that is initially locked in place. The cylinder contains a fixed amount of an ideal gas that is initially at room temperature and atmospheric pressure.

(a) The cylinder is placed in a hot-water bath. On the axes below, sketch a graph of pressure versus temperature for the process the gas undergoes as a result, and indicate the direction of the process on the graph.

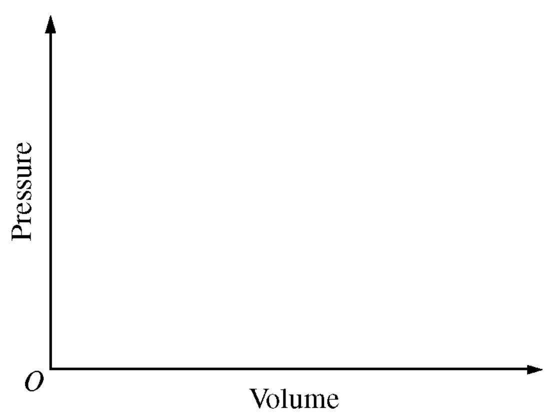


(b) The cylinder is removed from the hot-water bath. After equilibrium is reached, the lock is removed so the piston is free to move. Indicate whether the piston moves up, moves down, or remains stationary.

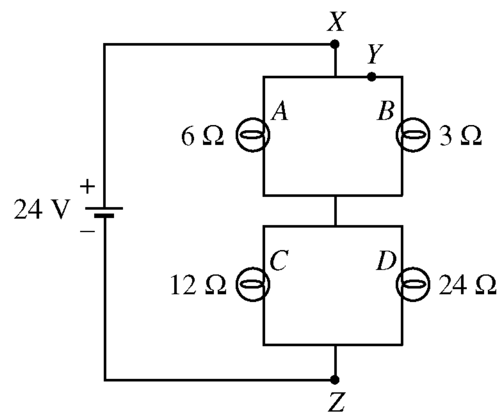
____ Moves up ____ Moves down ____ Remains stationary

Justify your answer.

(c) When the system is again at equilibrium, the piston is pushed down very slowly. On the axes below, sketch a graph of pressure versus volume for the process the gas undergoes as a result, and indicate the direction of the process on the graph. Label this process "C."



(d) Now the piston is pulled up quickly, so no heat is added to or removed from the gas during the process. On the axes above, sketch a graph of pressure versus volume for the process the gas undergoes as a result, and indicate the direction of the process on the graph. Label this process "D."



5. (15 points)

Four lightbulbs are connected in a circuit with a 24 V battery as shown above.

(a)

i. Determine the average potential energy change of an electron as it moves from point *Z* to point *X*.

ii. Indicate whether the electron gains or loses potential energy as it moves from point *Z* to point *X*.

____ Gains energy ____ Loses energy

(b) Calculate the equivalent resistance of the circuit.

(c)

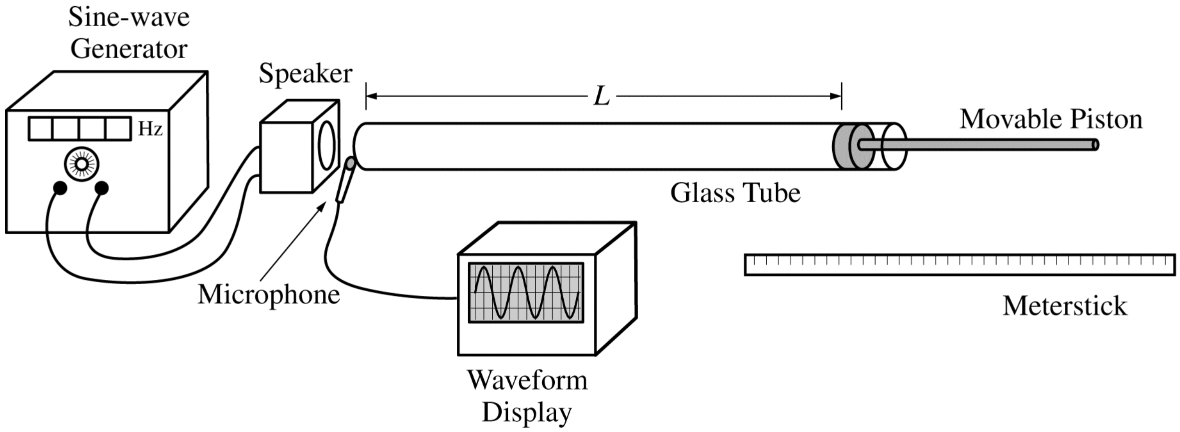
i. Calculate the magnitude of the current through point *Y*.

ii. Indicate on the diagram the direction of the current through point *Y*.

(d) Calculate the energy dissipated in the 12 Ω bulb in 5 s.

(e) Rank the bulbs in order of brightness, with 1 being the brightest. If any bulbs have the same brightness, give them the same ranking.

____ Bulb *A* ____ Bulb *B* ____ Bulb *C* ____ Bulb *D*



6. (10 points)

You are given the apparatus represented in the figure above. A glass tube is fitted with a movable piston that allows the indicated length L to be adjusted. A sine-wave generator with an adjustable frequency is connected to a speaker near the open end of the tube. The output of a microphone at the open end is connected to a waveform display. You are to use this apparatus to measure the speed of sound in air.

(a) Describe a procedure using the apparatus that would allow you to determine the speed of sound in air. Clearly indicate what quantities you would measure and with what instrument each measurement would be made. Represent each measured quantity with a different symbol.

(b) Using the symbols defined in part (a), indicate how your measurements can be used to determine an experimental value of the speed of sound.

(c) A more accurate experimental value can be obtained by varying one of the measured quantities to obtain multiple sets of data. Indicate one quantity that can be varied, and describe how a graph of the resulting data could be used to determine the speed of sound. Clearly identify independent and dependent variables, and indicate how the slope of the graph relates to the speed of sound.

7. (10 points)

The momentum of a particular proton is 5.5×10^{-20} kg•m/s. Relativistic effects can be ignored throughout this question.

(a) Calculate the de Broglie wavelength of the proton.

(b) Calculate the kinetic energy of the proton.

The proton is directed toward a very distant stationary uranium nucleus, $^{235}_{92}\text{U}$. The proton reaches a distance D from the center of the nucleus and then reverses direction. Assume that the nucleus is heavy enough to remain stationary during the interaction.

(c) Calculate the value of D.

(d) After the proton has moved away, the $^{235}_{92}\text{U}$ nucleus spontaneously fissions into $^{148}_{57}\text{La}$ and $^{84}_{35}\text{Br}$, along with three neutrons. As a result, 2.5×10^{-11} J of energy is released. Indicate whether the mass of the $^{235}_{92}\text{U}$ nucleus is greater or less than the mass of the fission products.

____ Greater ____ Less

Calculate the mass difference.

STOP

END OF EXAM