



AP[®] Physics B 2003 Free-Response Questions Form B

The materials included in these files are intended for use by AP teachers for course and exam preparation; permission for any other use must be sought from the Advanced Placement Program[®]. Teachers may reproduce them, in whole or in part, in limited quantities for noncommercial, face-to-face teaching purposes. This permission does not apply to any third-party copyrights contained herein. This material may not be mass distributed, electronically or otherwise. These materials and any copies made of them may not be resold, and the copyright notices must be retained as they appear here.

These materials were produced by Educational Testing Service[®] (ETS[®]), which develops and administers the examinations of the Advanced Placement Program for the College Board. The College Board and Educational Testing Service (ETS) are dedicated to the principle of equal opportunity, and their programs, services, and employment policies are guided by that principle.

The College Board is a national nonprofit membership association whose mission is to prepare, inspire, and connect students to college and opportunity. Founded in 1900, the association is composed of more than 4,300 schools, colleges, universities, and other educational organizations. Each year, the College Board serves over three million students and their parents, 22,000 high schools, and 3,500 colleges through major programs and services in college admissions, guidance, assessment, financial aid, enrollment, and teaching and learning. Among its best-known programs are the SAT[®], the PSAT/NMSQT[®], and the Advanced Placement Program[®] (AP[®]). The College Board is committed to the principles of equity and excellence, and that commitment is embodied in all of its programs, services, activities, and concerns.

For further information, visit www.collegeboard.com

Copyright © 2003 College Entrance Examination Board. All rights reserved. College Board, Advanced Placement Program, AP, AP Vertical Teams, APCD, Pacesetter, Pre-AP, SAT, Student Search Service, and the acorn logo are registered trademarks of the College Entrance Examination Board.

AP Central is a trademark owned by the College Entrance Examination Board. PSAT/NMSQT is a registered trademark jointly owned by the College Entrance Examination Board and the National Merit Scholarship Corporation. Educational Testing Service and ETS are registered trademarks of Educational Testing Service. Other products and services may be trademarks of their respective owners.

For the College Board's online home for AP professionals, visit AP Central at apcentral.collegeboard.com.

TABLE OF INFORMATION FOR 2003

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

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 B EQUATIONS FOR 2003

NEWTONIAN MECHANICS

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2} at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

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

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

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

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

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

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

$$K = \frac{1}{2} mv^2$$

$$\Delta U_g = mgh$$

$$W = \mathbf{F} \cdot \Delta \mathbf{r} = F\Delta r \cos \theta$$

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

$$P = \mathbf{F} \cdot \mathbf{v} = Fv \cos \theta$$

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

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

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

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

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

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

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

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
 $\mathbf{r}$ = position vector
 T = period
 t = time
 U = potential energy
 v = velocity or speed
 W = work done on a system
 x = position
 μ = coefficient of friction
 θ = angle
 τ = torque

ELECTRICITY AND MAGNETISM

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$$

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

$$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$$

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

$$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$$

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

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

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

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

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

$$V = IR$$

$$P = IV$$

$$C_p = \sum_i C_i$$

$$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$$

$$R_s = \sum_i R_i$$

$$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$$

$$F_B = qvB \sin \theta$$

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

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

$$\phi_m = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$$

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

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

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
 v = velocity or speed
 ρ = resistivity
 ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2003

FLUID MECHANICS AND THERMAL PHYSICS

$$p = p_0 + \rho gh$$

$$F_{\text{buoy}} = \rho Vg$$

$$A_1 v_1 = A_2 v_2$$

$$p + \rho gy + \frac{1}{2} \rho v^2 = \text{const.}$$

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

$$Q = mL$$

$$Q = mc\Delta T$$

$$p = \frac{F}{A}$$

$$pV = nRT$$

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

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$$

$$W = -p\Delta V$$

$$Q = nc\Delta T$$

$$\Delta U = Q + W$$

$$\Delta U = nc_V \Delta T$$

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

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

A = area
 c = specific heat or molar specific heat
 e = efficiency
 F = force
 h = depth
 K_{avg} = average molecular kinetic energy
 L = heat of transformation
 ℓ = length
 M = molecular mass
 m = mass of sample
 n = number of moles
 p = pressure
 Q = heat transferred to a system
 T = temperature
 U = internal energy
 V = volume
 v = velocity or speed
 v_{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

$$E = hf = pc$$

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

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

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

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

WAVES AND OPTICS

$$v = f\lambda$$

$$n = \frac{c}{v}$$

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

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

$$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$$

$$M = \frac{h_i}{h_o} = -\frac{s_i}{s_o}$$

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

$$d \sin \theta = m\lambda$$

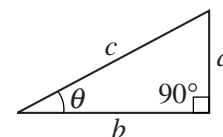
$$x_m \approx \frac{m\lambda L}{d}$$

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
 v = speed
 x = position
 λ = wavelength
 θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
 $A = bh$
 Triangle
 $A = \frac{1}{2}bh$
 Circle
 $A = \pi r^2$
 $C = 2\pi r$
 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



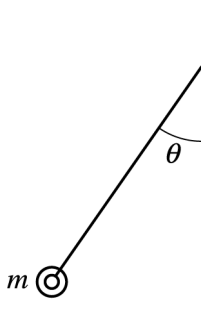
2003 AP[®] PHYSICS B FREE-RESPONSE QUESTIONS (Form B)

PHYSICS B SECTION II

Time—90 minutes

7 Questions

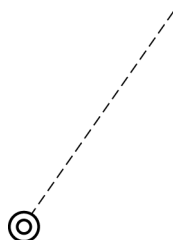
Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 15 minutes for answering each of questions 1-4, and about 10 minutes for answering each of questions 5-7. The parts within a question may not have equal weight. Show all your work in the goldenrod booklet in the spaces provided after each part, NOT in this lavender insert.



1. (15 points)

An airplane accelerates uniformly from rest. A physicist passenger holds up a thin string of negligible mass to which she has tied her ring, which has a mass m . She notices that as the plane accelerates down the runway, the string makes an angle θ with the vertical as shown above.

(a) In the space below, draw a free-body diagram of the ring, showing and labeling all the forces present.



The plane reaches a takeoff speed of 65 m/s after accelerating for a total of 30 s.

(b) Determine the minimum length of the runway needed.

(c) Determine the angle θ that the string makes with the vertical during the acceleration of the plane before it leaves the ground.

(d) What additional information would be needed in order to estimate the mechanical energy of the airplane at the instant of takeoff? Explain your answer.

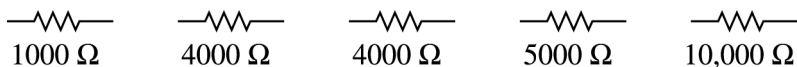
2003 AP[®] PHYSICS B FREE-RESPONSE QUESTIONS (Form B)

2. (15 points)

A student is asked to design a circuit to supply an electric motor with 1.0 mA of current at 3.0 V potential difference.

- (a) Determine the power to be supplied to the motor.
- (b) Determine the electrical energy to be supplied to the motor in 60 s.
- (c) Operating as designed above, the motor can lift a 0.012 kg mass a distance of 1.0 m in 60 s at constant velocity. Determine the efficiency of the motor.

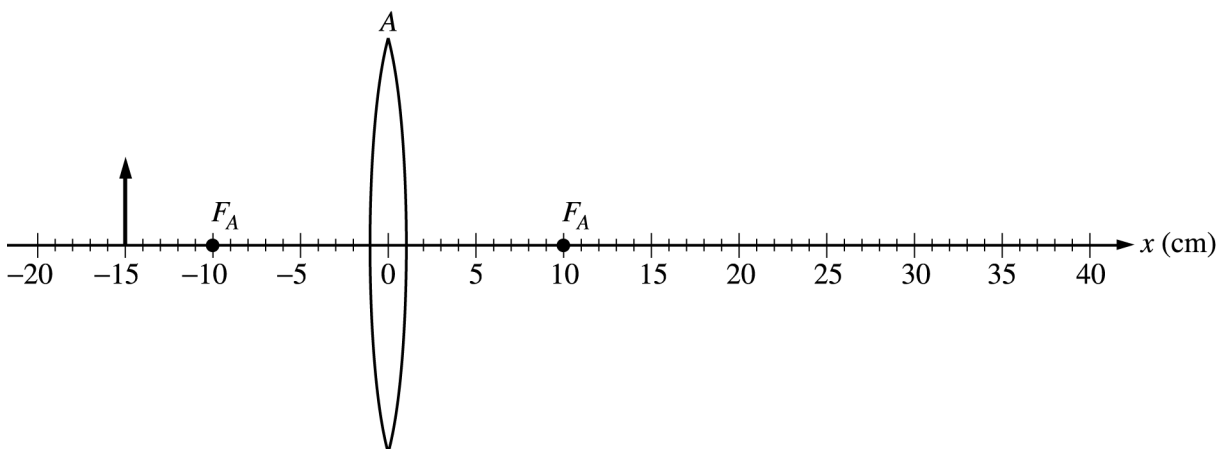
To operate the motor, the student has available only a 9.0 V battery to use as the power source and the following five resistors.



- (d) In the space below, complete a schematic diagram of a circuit that shows how one or more of these resistors can be connected to the battery and motor so that 1.0 mA of current and 3.0 V of potential difference are supplied to the motor. Be sure to label each resistor in the circuit with the correct value of its resistance.



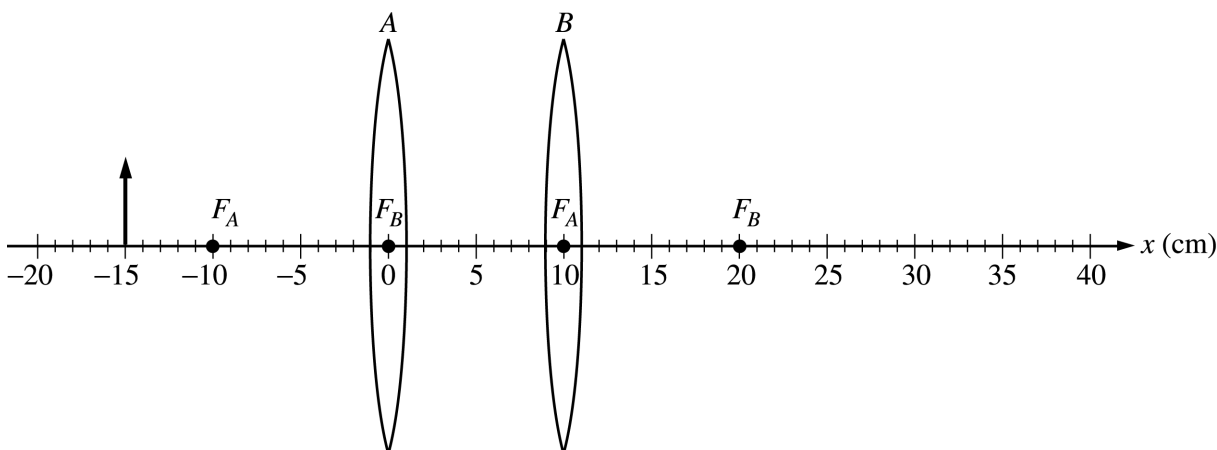
2003 AP[®] PHYSICS B FREE-RESPONSE QUESTIONS (Form B)



3. (15 points)

A thin convex lens A of focal length $f_A = 10$ cm is positioned on an x -axis as shown above. An object of height 5 cm, represented by the arrow, is positioned 15 cm to the left of lens A .

- On the figure above, draw necessary rays and sketch the image produced by lens A .
- Calculate the location of the image produced by lens A .
- Calculate the height of the image produced by lens A .



A second thin convex lens B of focal length $f_B = 10$ cm is now positioned 10 cm to the right of lens A , as shown above.

- Determine the location on the x -axis given above of the final image produced by the combination of lenses.
- Check the appropriate spaces below to indicate the characteristics of the final image produced by the combination of lenses.

____ inverted

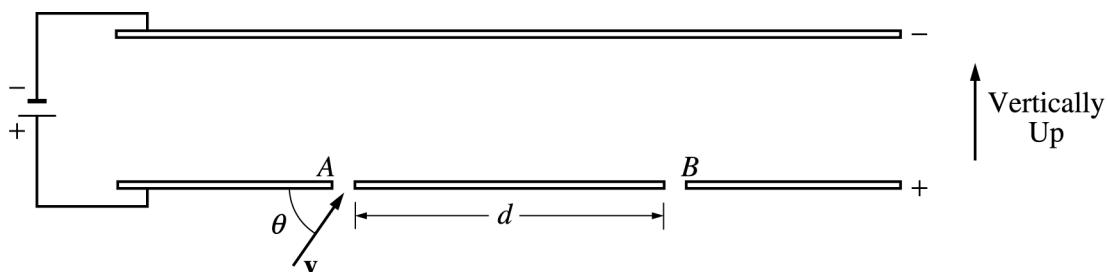
____ larger than the original object

____ upright

____ smaller than the original object

Explain your answers.

2003 AP[®] PHYSICS B FREE-RESPONSE QUESTIONS (Form B)



4. (15 points)

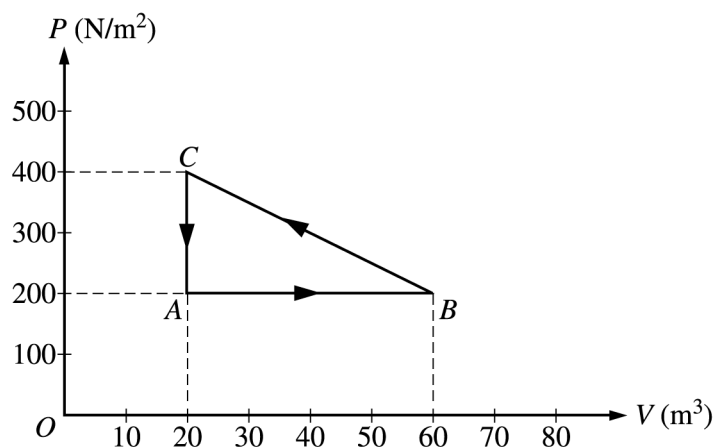
An electric field $\mathbf{E}$ exists in the region between the two electrically charged parallel plates shown above. A beam of electrons of mass m , charge q , and velocity $\mathbf{v}$ enters the region through a small hole at position A . The electrons exit the region between the plates through a small hole at position B . Express your answers to the following questions in terms of the quantities m , q , $\mathbf{E}$, θ , and $\mathbf{v}$. Ignore the effects of gravity.

- (a)
 - i. On the diagram of the parallel plates above, draw and label a vector to show the direction of the electric field $\mathbf{E}$ between the plates.
 - ii. On the following diagram, show the direction of the force(s) acting on an electron after it enters the region between the plates.



- iii. On the diagram of the parallel plates above, show the trajectory of an electron that will exit through the small hole at position B .
- (b) Determine the magnitude of the acceleration of an electron after it has entered the region between the parallel plates.
- (c) Determine the total time that it takes the electrons to go from position A to position B .
- (d) Determine the distance d between positions A and B .
- (e) Now assume that the effects of gravity cannot be ignored in this problem. How would the distance d change for an electron entering the region at A and leaving at B ? Explain your reasoning.

2003 AP[®] PHYSICS B FREE-RESPONSE QUESTIONS (Form B)



5. (10 points)

One mole of an ideal gas is taken around the cycle $A \rightarrow B \rightarrow C \rightarrow A$ as shown on the PV diagram above.

(a) Calculate the temperature of the gas at point A .

(b) Calculate the net work done on the gas during one complete cycle.

(c) i. Is heat added to or removed from the gas during one complete cycle?

_____ added to the gas _____ removed from the gas

ii. Calculate the heat added to or removed from the gas during one complete cycle.

(d) After one complete cycle, is the internal energy of the gas greater, less, or the same as before?

_____ greater _____ less _____ the same

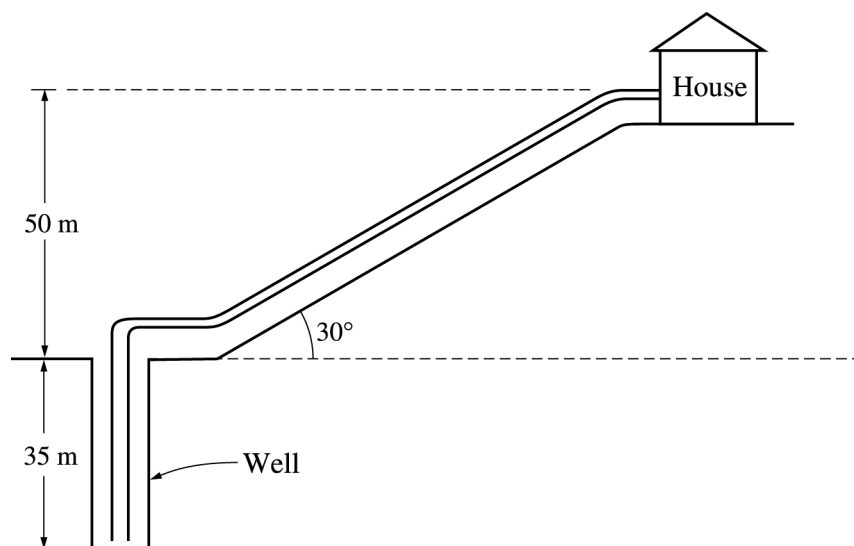
Justify your answer.

(e) After one complete cycle, is the entropy of the gas greater, less, or the same as before?

_____ greater _____ less _____ the same

Justify your answer.

2003 AP[®] PHYSICS B FREE-RESPONSE QUESTIONS (Form B)



6. (10 points)

A pump, submerged at the bottom of a well that is 35 m deep, is used to pump water uphill to a house that is 50 m above the top of the well, as shown above. The density of water is $1,000 \text{ kg/m}^3$. All pressures are gauge pressures. Neglect the effects of friction, turbulence, and viscosity.

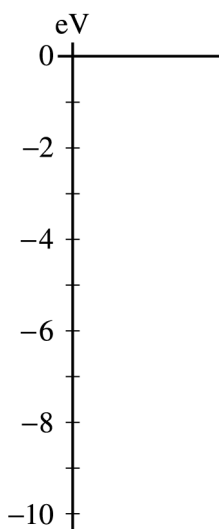
- (a) Residents of the house use 0.35 m^3 of water per day. The day's pumping is completed in 2 hours during the day.
 - i. Calculate the minimum work required to pump the water used per day
 - ii. Calculate the minimum power rating of the pump.
- (b) The average pressure the pump actually produces is $9.20 \times 10^5 \text{ N/m}^2$. Within the well the water flows at 0.50 m/s and the pipe has a diameter of 3.0 cm. At the house the pipe diameter is 1.25 cm.
 - i. Calculate the flow velocity when a faucet in the house is open.
 - ii. Explain how you would calculate the minimum pressure at the faucet.

2003 AP[®] PHYSICS B FREE-RESPONSE QUESTIONS (Form B)

7. (10 points)

An experiment is performed on a sample of atoms known to have a ground state of -5.0 eV. The gas is illuminated with “white light” (400 - 700 nm). A spectrometer capable of analyzing radiation in this range is used to measure the radiation. The sample is observed to absorb light at only 400 nm. After the “white light” is turned off, the sample is observed to emit visible radiation of 400 nm and 600 nm.

- (a) In the space below, determine the values of the energy levels and on the following scale sketch an energy-level diagram showing the energy values in eVs and the relative positions of:
- the ground state
 - the energy level to which the system was first excited
 - one other energy level that the experiment suggests may exist



- (b) What is the wavelength of any other radiation, if any, that might have been emitted in the experiment?
Why was it not observed?

END OF EXAMINATION