AP Physics B
2000 Scoring Guidelines

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 dedicated to preparing, inspiring, and connecting students to college and opportunity. Founded in 1900, the association is composed of more than 3,900 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 admission, guidance, assessment, financial aid, enrollment, and teaching and learning. Among its best-known programs are the SAT®, the PSAT/NMSQT™, the Advanced Placement Program® (AP®), and Pacesetter®. 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.

2000 Physics B Solutions **Distribution of points**

Question 1 (15 points)

(a) 1 point

The cart is at rest at $t = 4$ s and 18 s.
For indicating both times that the car is at rest and not including any incorrect times — 1 point

(b) 2 points

The speed of the cart is increasing during the intervals $t =$ 4 to 9 s and 18 to 20 s.
For each correct time interval one point was awarded. — 2 points

One point was deducted for each incorrect interval, for a maximum two-point deduction.

(c) 3 points

For indicating that the change in position is equal to the area under the graph, or for using an appropriate kinematic equation with non-zero initial velocity — 1 point

$\Delta x =$ area OR, for example, $\Delta x = v_i t + \frac{1}{2} a t^2$

For correct substitution of values — 1 point

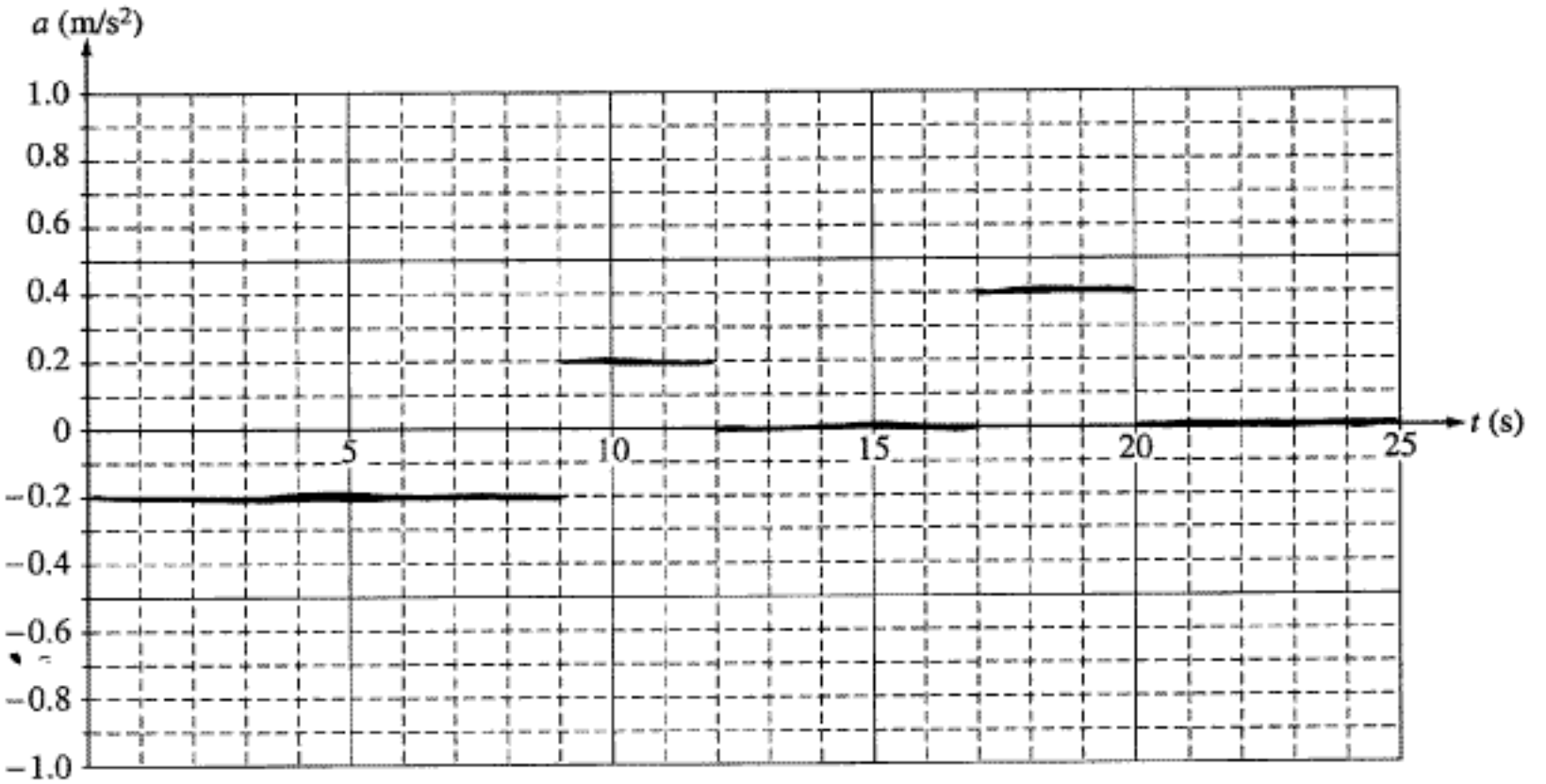
$\Delta x = \frac{1}{2}(4\text{ s})(0.8\text{ m/s}) + \frac{1}{2}(5\text{ s})(-1\text{ m/s})$

OR $\Delta x = (0.8\text{ m/s})(9\text{ s}) + \frac{1}{2}\left(-0.2\text{ m/s}^2\right)(9\text{ s})^2$

$\Delta x = -0.9$ m
For adding the initial position to Δx — 1 point
$x = x_0 + \Delta x = 2\text{ m} + (-0.9\text{ m})$
$x = 1.1$ m

Question 1 (continued)

(d) 3 points



For indicating that the acceleration is zero during the intervals of constant velocity, 12 to 17 s and 20 to 25 s — 1 point

For indicating that the acceleration is negative and constant from zero to 9 s, and positive and constant from 9 to 11 s and 17 to 20 s — 1 point

For having the correct values for two of the three intervals of non-zero acceleration: $-0.20\ \text{m/s}^2$, $+0.20\ \text{m/s}^2$, and $+0.40\ \text{m/s}^2$ — 1 point

(e)

i. 1 point

For using the correct kinematic equation, with the initial vertical velocity equal to zero — 1 point

$$y = \frac{1}{2} gt^2$$

Solving for t:

$$t = \sqrt{2y/g}$$

$$t = \sqrt{2(0.40\ \text{m})/10\ \text{m/s}^2}$$

$t = 0.28$ s (or 0.29 s using $g = 9.8\ \text{m/s}^2$)

Question 1 (continued)

(e) (continued)

ii. 2 points

Using the kinematic equation for the horizontal motion:

$x = v_x t$

For using the correct value for the horizontal speed — 1 point

$v_x = 0.8$ m/s

$x = (0.8 \text{ m/s})(0.28 \text{ s})$

For the correct answer — 1 point

$x = 0.22$ m (or 0.23 m using $g = 9.8 \text{ m/s}^2$)

iii. 3 points

For correctly applying conservation of energy — 2 points

$K_{bottom} = K_{top} + U_{top}$

$K_{bottom} = \frac{1}{2} m v_x^2 + mgy$

$K_{bottom} = \frac{1}{2}(0.50 \text{ kg})(0.8 \text{ m/s})^2 + (0.50 \text{ kg})(10 \text{ m/s}^2)(0.40 \text{ m})$

For the correct answer — 1 point

$K_{bottom} = 2.2$ J (or 2.1 J using $g = 9.8 \text{ m/s}^2$)

In the absence of any of the above credit, one point was awarded for any recognition that the vertical velocity changes.

(Alternate solution) — *(Alternate points)*

For any recognition that the vertical velocity changes. — *1 point*

Calculating the y-component of velocity at the bottom:

$v_y = v_{yi} - gt$

$v_y = 0 + (10 \text{ m/s}^2)(0.28 \text{ s}) = 2.8 \text{ m/s}$

For correctly calculating the total speed from the components — *1 point*

$v^2 = v_x^2 + v_y^2$

$v = \sqrt{(0.8 \text{ m/s})^2 + (2.8 \text{ m/s})^2}$

$v = 2.9$ m/s

For correctly calculating the final kinetic energy — *1 point*

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

$K = \frac{1}{2}(0.50 \text{ kg})(2.9 \text{ m/s})^2$

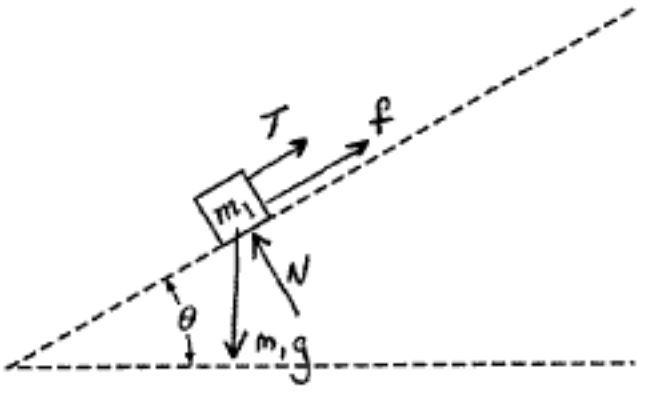
$K = 2.2$ J (or 2.1 J depending on the value of g used and amount of rounding in intermediate calculations)

2000 Physics B Solutions

Distribution of points

Question 2 (15 points)

(a) 4 points



For each correctly drawn and labeled force one point was awarded (Credit was awarded for any reasonable placement of forces) — 4 points

In the absence of the total weight, showing both components $m_1 g \sin\theta$ and $m_1 g \cos\theta$ received credit

One point was deducted from earned credit for one or more obvious incorrect forces (no penalty for showing both weight and its components)

(b) 3 points

Using the expression for frictional force:
$f = \mu N$

For a correct substitution for the normal force — 1 point
$N = m_1 g \cos\theta$

For correctly solving for the coefficient of friction — 1 point

$$\mu = \frac{f}{m_1 g \cos\theta}$$

For an answer correctly expressed in terms of the given quantities — 1 point

For example, beginning with the equation $f + T_1 - m_1 g \sin\theta = 0$ for block 1, substituting for f and solving for μ yields $\mu = \dfrac{m_1 g \sin\theta - T_1}{m_1 g \cos\theta}$, which receives credit for the first two points.

Since only one block is involved in this part, no penalty was assessed for omitting the subscript on the mass variable.

Question 2 (continued)

(c) 5 points

For an indication that the acceleration or the net force is zero — 1 point

Using Newton's second law:

$\Sigma \mathbf{F} = 0$

Applying this to the three-block system, with the tensions treated as internal forces (so they do not appear in the equation):

$-m_1 g \sin\theta + f - m_2 g \sin\theta + 2f + Mg = 0$

For the correct weight components, with correct signs, in the above equation — 1 point

For the correct friction terms, with correct signs — 1 point

Solving for Mg:

$Mg = m_1 g \sin\theta - f + m_2 g \sin\theta - 2f$

For the correct answer in terms of the given quantities — 2 points

$$M = (m_1 + m_2)\sin\theta - \frac{3f}{g}$$

Only one point was awarded for a correct answer in terms of quantities other than the given ones

Alternate solutions containing a set of equations from which tensions should be eliminated were awarded similar credit. For example, credit for the second and third points above could be earned for correctly written equations even if no attempt was made to solve them. Two possible sets of equations:

Set 1 -- $-f + T_1 - m_1 g \sin\theta + 2f + T_2 - m_2 g \sin\theta - T_1 = (m_1 + m_2)a$ and $Mg - T_2 = Ma$

Set 2 -- $m_1 g \sin\theta = f + T_1$ and $T_1 + m_2 g \sin\theta = 2f + T_2$ and $Mg = T_2$

(This set also earns credit for the first point.)

(d) 3 points

Applying Newton's second law:

$m_1 g \sin\theta - f = m_1 a$

For correctly including friction in the equation — 1 point

For correctly including the weight component in the equation — 1 point

For the correct answer in terms of the given quantities — 1 point

$$a = g \sin\theta - \frac{f}{m_1}$$

Since only one block is involved in this part, no penalty was assessed for omitting the subscript on the mass variable.

2000 Physics B Solutions **Distribution of points**

Question 3 (15 points)

(a) 5 points

For determining the net resistance of the two parallel resistors — 1 point

$$\frac{1}{R_{\parallel}} = \frac{1}{R} + \frac{1}{R} = \frac{2}{R}$$

$$R_{\parallel} = \frac{R}{2}$$

For determining the total resistance of the circuit — 1 point

$$R_T = R + \frac{R}{2}$$

$$R_T = \frac{3R}{2}$$

Using Ohm's law:
$I = V/R$

For correctly substituting values that apply to the entire circuit to determine the total current — 1 point

$$I = \frac{30\text{V}}{(3R/2)}$$

$$I = \frac{20\text{ V}}{R}$$

For correctly substituting values applying to the resistor across which the voltmeter is connected — 1 point

$$V = \frac{20}{R} R$$

For the correct answer — 1 point

$V = 20$ V

Since all three resistors have equal values, it is possible to compare the resistance of the parallel combination to the total resistance and then split the voltage correctly with a minimum of written calculation. Full credit could be earned for this approach.

(b) 2 points

For using the equation relating capacitance, voltage, and charge — 1 point

$Q = CV$

For correct substitution — 1 point

$$Q = \left(1 \times 10^{-9}\text{ F}\right)(30\text{ V})$$

$$Q = 3 \times 10^{-8}\text{ C}$$

2000 Physics B Solutions **Distribution of points**

Question 3 (continued)

(c)

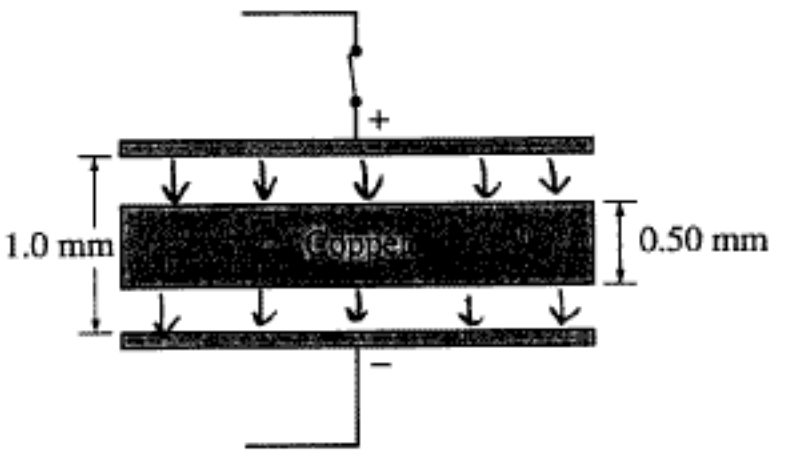
i. 1 point

The 30 V battery is still connected across the capacitor and there is no current, so the potential difference remains the same.
For indicating that the potential between the plates is 30 V — 1 point

ii. 1 point

At equilibrium, the field inside any conductor is zero.
For indicating that the electric field inside the copper block is zero — 1 point

iii. 3 points



For arrows directed down between the top plate and the copper block — 1 point
For having no arrows inside the copper block — 1 point
For arrows directed down between the copper block and the lower plate — 1 point

No credit was awarded if there was nothing drawn between the plates

iv. 3 points

For using the equation relating voltage, electric field, and plate separation for a parallel plate capacitor — 1 point

$$E = \frac{V}{d}$$

For correct substitution of consistent values — 1 point

$$E = \frac{30\ \text{V}}{0.5\ \text{mm}} \quad \text{OR} \quad E = \frac{15\ \text{V}}{0.25\ \text{mm}}$$

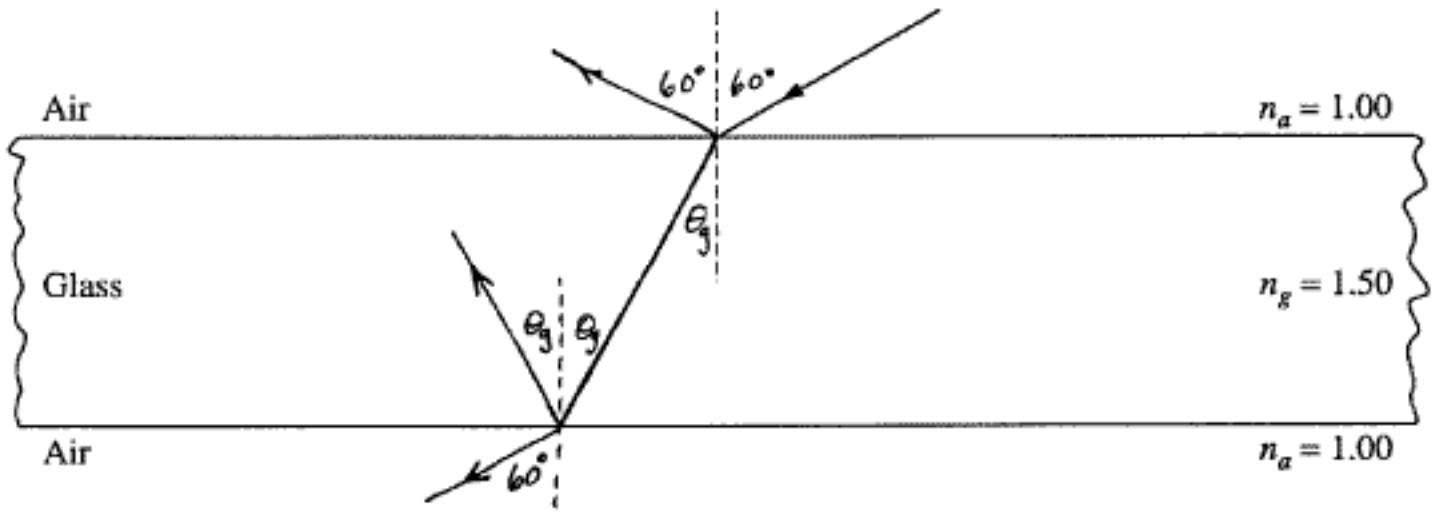
For the correct answer with proper units — 1 point

$E = 60$ V/mm OR 60,000 V/m

2000 Physics B Solutions **Distribution of points**

Question 4 (15 points)

(a) 8 points



For correctly labeling the initial 60° angle of incidence — 1 point

For each correctly drawn ray with angle of reflection or refraction labeled one point was awarded — 4 points

For correctly labeling the angle of incidence at the lower interface — 1 point

Using Snell's law:

$n_a \sin \theta_a = n_g \sin \theta_g$

For correct substitution — 1 point

$1.0 \sin 60° = 1.5 \sin \theta_g$

For the correct value of θ_g — 1 point

$\theta_g = 35.3°$ OR 0.61 rad

At each interface, only one point was awarded for a correct sketch of rays with incorrect or missing angle labels.

At each interface, one point was deducted for an incorrect sketch with correct angle labels.

(b)

i. 2 points

Using the relationship between frequency and wavelength:

$c = f\lambda$

For substituting the correct values in air — 1 point

$$f_a = \frac{c}{\lambda_a} = \frac{3 \times 10^8 \text{ m/s}}{5.25 \times 10^{-7} \text{ m}}$$

For the correct answer — 1 point

$f_a = 5.71 \times 10^{14}$ Hz

Question 4 (continued)

ii. 1 point

For a correct answer — 1 point
$f_f = 5.71 \times 10^{14}$ Hz OR indicating it's the same value as part i

iii. 2 points

For correctly applying one or more equations, including substitution — 1 point

$\lambda_f = \frac{\lambda_a}{n_f}$ OR $v_f = \frac{c}{n_f}$ and $\lambda_f = \frac{v_f}{f_f}$

$\lambda_f = \frac{5.25 \times 10^{-7} \text{ m}}{1.38}$ OR $\lambda_f = \frac{(3 \times 10^8 \text{ m/s})/1.38}{5.71 \times 10^{14} \text{ Hz}}$

For the correct answer, with proper units — 1 point
$\lambda_f = 3.8 \times 10^{-7}$ m OR 380 nm

iv. 2 points

For indicating the correct condition for constructive interference — 1 point
$2L = \lambda_f$

$2L = 3.8 \times 10^{-7}$ m

For the correct answer, with proper units — 1 point
$L = 1.9 \times 10^{-7}$ m OR 190 nm

2000 Physics B Solutions **Distribution of points**

Question 5 (10 points)

(a)

i. 2 points

The maximum kinetic energy of the electrons is equal to the work done as they are decelerated by the potential difference that is required to stop the photoelectric current.

$K_{max} = qV$

$K_{max} = e(4.5\text{ V})$, where e is the charge of an electron OR $(1.6 \times 10^{-19}\text{ C})(4.5\text{ V})$

$K_{max} = 4.5\text{ eV}$ OR $7.2 \times 10^{-19}\text{ J}$

For a correct numerical answer — 1 point

For correct units — 1 point

ii. 3 points

Using the definition of kinetic energy:

$K_{max} = \frac{1}{2} m v_{max}^2$

$v_{max} = \sqrt{2K_{max}/m}$

For substituting the value of K_{max} from part i — 1 point

For converting eV to joules — 1 point

(If part i was calculated in joules, this point was awarded for making the conversion there)

$v_{max} = \sqrt{2(4.5\text{ eV})(1.6 \times 10^{-19}\text{ J/eV})/9.11 \times 10^{-31}\text{ kg}}$

OR $\sqrt{2(7.2 \times 10^{-19}\text{ J})/9.11 \times 10^{-31}\text{ kg}}$

For the correct answer — 1 point

$v_{max} = 1.26 \times 10^{6}\text{ m/s}$

(b) 3 points

For a correct equation for energy in terms of wavelength — 1 point

$E = \frac{hc}{\lambda}$

$\lambda = \frac{hc}{E}$

For substituting the correct total energy into the equation above — 1 point

$\lambda = \frac{1.24 \times 10^{3}\text{ eV nm}}{(4.5 + 2.3)\text{ eV}}$

For the correct answer — 1 point

$\lambda = 1.83 \times 10^{-7}\text{ m}$

Question 5 (continued)

(c) 2 points

Using the photoelectric equation:

$K_{max} = hf - \phi$

For the correct expression for the minimum frequency (i.e. with $K_{max} = 0$) — 1 point

$$f_0 = \frac{\phi}{h}$$

$$f_0 = \frac{2.3 \text{ eV}}{4.14 \times 10^{-15} \text{ eV s}}$$

For the correct answer — 1 point

$f_0 = 5.56 \times 10^{14}$ Hz

2000 Physics B Solutions

Question 6 (10 points)

The most common approach used by students was calorimetry. They typically used water or a block of metal as the material of known specific heat that was to be heated to a known temperature, and used to transfer energy to the unknown liquid. Another method was immersion of an electrical heater, where measurement of current, voltage, and the time of immersion could be used to calculate the energy transfer.

(a) 2 points

2 points awarded	1 point awarded	No credit awarded
Diagram is provided and labeled where necessary for clarity and Equipment list is complete (i.e., equipment necessary to do the experiment is described)	Equipment list is provided and is complete but there is no diagram	Only a partial equipment list is provided
	OR Equipment list and diagram are provided but some equipment is missing	OR Only an unlabeled diagram is provided (In this case credit can still be earned for later parts.)
OR Diagram is provided with all equipment clearly labeled	OR Drawings of individual, labeled pieces of equipment is provided but the setup is not shown	

(b) 2 points

2 points awarded	1 point awarded	No credit awarded
Complete list of measurements is provided (i.e., all measurements necessary to do the proper calculations) and A symbol is assigned to each quantity	An incomplete listing of measurements and symbols is provided	The list of measurements provided does not lead to a productive experiment
	OR A list of measurements with no symbols is provided	

Continued on next page

Question 6 (continued)

(c) 3 points

3 points awarded	2 points awarded	1 point awarded	No credit awarded
Statement of conservation of energy is included and All relevant variables are substituted correctly to form an equation and Sign conventions are used correctly throughout	Response correct at 3-point level, but heat exchange with container is not considered (unless the container is specifically stated as made of styrofoam, etc.) OR Response correct at 3-point level except signs of terms are incorrect Note: If $Q = mc\Delta T$ appears, with Q defined in (b) or (c) as the heat transferred to the liquid, and ΔT defined as a measured quantity, two points are awarded (one point for energy conservation and one pt for the correct sign)	Only conservation of energy is stated	$Q = mc\Delta T$ stated with no definition of Q

(d) 2 points

2 points awarded	1 point awarded	No credit awarded
Statement of at least one reasonable source of experimental error, with no incorrect sources of error and Correct justification of the effect on the value of specific heat obtained	Statement of at least one reasonable source of error, with no justification or an inappropriate justification OR Reasonable source(s) of error listed, along with an appropriate justification, but incorrect source(s) or justification(s) also given	Neither source of error nor justification relates reasonably to the method used

Feasibility 1 point

One additional point was awarded if a practical and feasible experimental method is described overall (i.e., enough information is given throughout the problem that the reader judges it to be feasible --- even if it is not described explicitly).

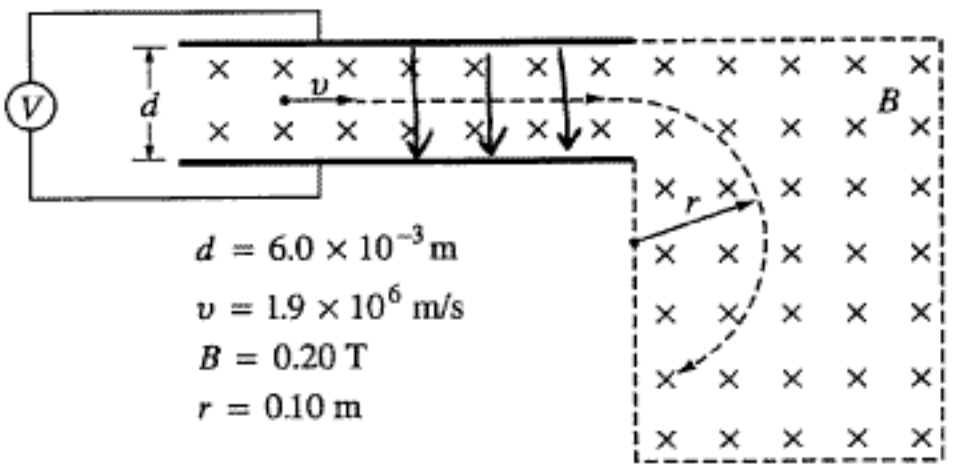
2000 Physics B Solutions **Distribution of points**

Question 7 (10 points)

(a) 2 points

For indicating that the particle has a negative charge — 1 point
For a reasonable justification that considers the particle's behavior in the region of magnetic field outside the space between the plates. — 1 point
For example: By the right-hand rule, the directions of the velocity and the magnetic field indicate that a positive charge would move in a circular path curving above the plates. Since the curve is in the opposite direction the charge must be negative.

(b) 2 points



$d = 6.0 \times 10^{-3}$ m
$v = 1.9 \times 10^{6}$ m/s
$B = 0.20$ T
$r = 0.10$ m

For indicating a vertical field only in the region between the plates, and not extending outside that region — 1 point
For indicating that the field is downward — 1 point

(c) 3 points

For a correct relationship between the potential difference and the electric field — 1 point
$E = V/d$
Between the plates, the electric and magnetic forces must be equal in order for the particle to pass through undeflected
For a correct expression relating the electric and magnetic fields — 1 point
$qE = qvB$
Substituting for the electric field and solving for the potential:
$V = vBd$
$V = (1.9 \times 10^{6}\ \text{m/s})(0.20\ \text{T})(6 \times 10^{-3}\ \text{m})$
For the correct answer — 1 point
$V = 2300$ V

Question 7 (continued)

(d) 3 points

For correctly relating the centripetal and magnetic forces on the particle — 1 point

$$\frac{mv^2}{r} = qvB$$

For the correct expression for $\frac{q}{m}$ — 1 point

$$\frac{q}{m} = \frac{v}{rB}$$

$$\frac{q}{m} = \frac{1.9 \times 10^6 \text{ m/s}}{(0.10 \text{ m})(0.20 \text{ T})}$$

For a correct answer — 1 point

$$\frac{q}{m} = 9.5 \times 10^7 \text{ C/kg}$$