Introduction:

In this task you will be asked to assess the quality of student solutions to a physics exam problem using a prescribed scoring technique. Your scores and comments are meant to help you reflect on your own teaching practices.

Instructions for the scoring task:

There are two parts to this task. The first part will be a take-home exercise in preparation for the second part.

PART I (To be done **BEFORE** the problem-solving session): This is the preparation for your evaluating student problem solutions in tomorrow's class.

1. Read "What is Problem Solving?" by M. A. Martinez in Section 3 of your selected reading packet.
2. Write down your solution to the provided physics problem. This is the problem the students solved.
3. After you have a written problem solution, compare it to the instructor's solution (other side). Note that there are two possible solutions, and the problem requires a unit conversion.
4. You have 6 student solutions to this problem labeled F – K. Give each of them a grade of 0 and 25 with 25 being a perfect solution. Just use your judgment to determine the grade. You will report these grades in class. For reference here is a mapping of numerical grades to letter grades used by some of the classes:
   A : 25-21 B: 20-17 C: 16-14 D : 13-11 F : 10-0

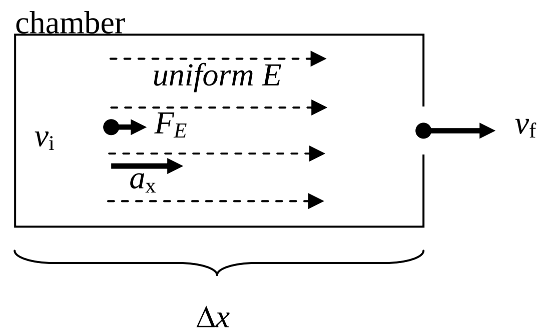
   The University grading policy gives the meaning of these grades as:
   A - Represents achievement that is outstanding relative to the level necessary to meet course requirements
   B - Represents achievement that is significantly above the level necessary to meet course requirements
   C - Represents achievement that meets the course requirements in every respect
   D - Represents achievement that is worthy of credit even though it fails to meet fully the course requirements
5. Read the scoring document (rubric) and category descriptions printed after these instructions. If there is anything you find unclear in the wording, write down your comments on page 2 of the scoring sheet (last page of the packet). Write down any features of a good problem solution that are not represented by these categories.

Problem:

You are designing part of a machine to detect carbon monoxide (CO) molecules (28 g/mol) in a sample of air. In this part, ultraviolet light is used to produce singly charged ions (molecules with just one missing electron) from air molecules at one side of a chamber. A uniform electric field then accelerates these ions from rest through a distance of 0.8 m through a hole in the other side of the chamber. Your job is to calculate the direction and magnitude of the electric field needed so that CO^+ ions created at rest at one end will have a speed of 8×10^4 m/s when they exit the other side.

Example Instructor Solution:

Description



$v_i = 0$; initial velocity of the CO^+ molecule
$v_f = 8x10^4$m/s; final velocity of the CO^+ molecule
E: uniform electric field in the chamber
$\Delta x = 0.8$m; distance to hole in chamber
q = $1.602x10^{-19}$C; charge of a CO^+ molecule
m = mass of a CO^+ molecule
a_x= acceleration of the CO^+ molecule
F_E = force on the CO^+ molecule in the uniform electric field

Target: calculate the electric field, *E*

Solution Approach 1: Use Newton's Second Law to relate the force on the molecule to its acceleration; use kinematics to write an expression for acceleration in terms of velocity and distance. Assume gravity is negligible. Convert the mass of CO into kilograms per molecule.

$$\sum F_X = ma_X : \qquad qE = ma_X \quad \textit{solve for the electric field}: E = \frac{ma_X}{q}$$

$$v_f^2 = v_i^2 + 2a_X\Delta x \quad \textit{solve for acceleration}: \ a_X = \frac{v_f^2 - v_i^2}{2\Delta x}$$

$$m = \frac{28g}{mol} = \frac{0.028kg}{mol} \bullet \frac{1mol}{6.022\times10^{23} molecules} \approx 4.65\times10^{-26} kg/moleculeCO^+$$

$$E = \frac{m\left(v_f^2 - v_i^2\right)}{2q\Delta x} = \frac{4.65\times10^{-26}kg\left(\left(8\times10^4 m/s\right)^2 - 0\right)}{2\left(1.602\times10^{-19}C\right)\left(0.8m\right)} = \boxed{1160\,N/C} \ \textit{direction is same as } v\ (\textit{to the right.})$$

Solution Approach 2: Use conservation of energy to relate the electric potential energy transferred to the molecule and its final kinetic energy. Assume gravity is negligible. Convert the mass of CO into kilograms per molecule.

$$E_{final} - E_{initial} = E_{in} - E_{out} : \qquad \frac{1}{2}mv_f{}^2 - \frac{1}{2}mv_i{}^2 = q\Delta V - 0 \ \ OR \ \ \frac{1}{2}mv^2 - \frac{1}{2}mv_i{}^2 = \int \vec{F}\cdot d\vec{s} - 0$$

$$\textit{for uniform electric field}: \ \Delta V = \int \vec{E}\cdot d\vec{s} = E\Delta x \quad \textit{and} \quad \int \vec{F}\cdot d\vec{s} = F_E\Delta x = qE\Delta x$$

$$\frac{1}{2}mv_f{}^2 - \frac{1}{2}mv_i{}^2 = qE\Delta x \ \ \textit{solve for electric field}$$

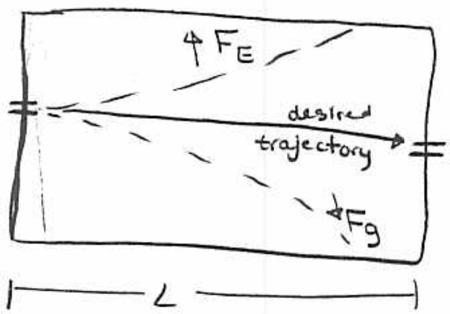
$$m = \frac{28g}{mol} = \frac{0.028kg}{mol} \bullet \frac{1mol}{6.022\times10^{23} molecules} \approx 4.65\times10^{-26} kg/molecule\ CO^+$$

$$E = \frac{m\left(v_f^2 - v_i^2\right)}{2q\Delta x} = \frac{4.65\times10^{-26}kg\left(\left(8\times10^4 m/s\right)^2 - 0\right)}{2\left(1.602\times10^{-19}C\right)\left(0.8m\right)} = \boxed{1160\,N/C} \ \textit{direction is same as } v\ (\textit{to the right.})$$

Check: The units are correct for electric field. We expect that for a particle with larger mass or higher final velocity the electric field would need to be stronger, which is consistent with the equation obtained.

F

picture:



$q = e \ (= +1.602 \times 10^{-19} C)$

$v_i = 0 \ m/s$

$v_f = 8 \times 10^4 \ m/s$

$m = 28 \ g/mol$

$L = 0.8 \ m$

Question: What magnitude and direction of an electric field should be used for charged particles to reach a velocity of 8×10^4 m/s and experience no net force to make it through the hole on the other side?

Approach: Use Newton's Laws to find the value of $\vec{F}_E$ and then use that information to solve for $\vec{E}$.

$F_{total} = F_E + F_g = 0 \rightarrow F_g = |-F_E| \longrightarrow mg = qE$

and $\vec{E} = \dfrac{\vec{F}_E}{q_0}$ $\qquad \vec{F}_E = q\vec{E}$

$\boxed{E = \dfrac{mg}{q}}$

$F_g = mg \rightarrow m: \dfrac{28 \ \cancel{g}}{\cancel{mol} \ CO} \cdot \dfrac{1 \ \cancel{mol}}{6.02 \times 10^{23} \ molecule} \cdot \dfrac{1 \ kg}{1000 \ \cancel{g}} = 4.65 \times 10^{-26} \ kg/molecule$

$F_g = (4.65 \times 10^{-26} \ kg)(9.8 \ m/s^2) = 4.56 \times 10^{-25} \ N$

$4.56 \times 10^{-25} \ N = qE \rightarrow E = \dfrac{4.56 \times 10^{-25} N}{q} = \dfrac{4.56 \times 10^{-25} N}{1.602 \times 10^{-19} C}$

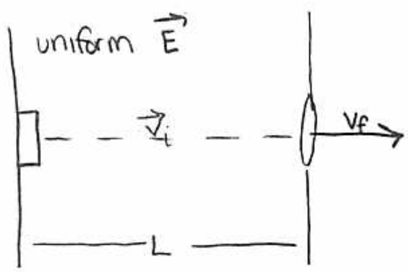
$\boxed{E = 2.85 \times 10^{-6} \ \frac{N}{C} \text{ straight upward}}$

check units: $\frac{N}{C}$ is correct for

G

Focus the Problem

Diagram:



$v_f = 8 \times 10^4$ m/s

$L = 0.8$ m

Question:

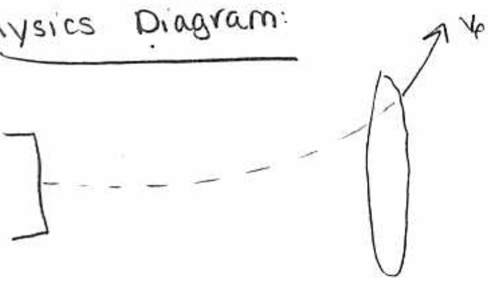
What is the direction & magnitude of the electric field such that the final velocity of the ion is 8×10^4 m/s?

Approach:

use $\vec{E} = \frac{\vec{F}}{q_0}$, dynamics, Newton's Laws ($F = ma$), & kinematics to determine $\vec{E}$ field; find magnitude 1st then decide direction

Planning the Solution:

Physics Diagram:



$\vec{E} = \frac{\vec{F}}{q_0}$ $\quad F = ma \quad$ $a = \frac{v^2}{R}$

$E_f - E_{in} = 0$

$\Rightarrow E_f = E_i$

Solving the Problem:

① $a = \frac{v^2}{R}$ } know all but a

② plug ① into $F = ma$

$\Rightarrow F = \frac{mv^2}{R}$

③ $E = \frac{F}{q}$

$\Rightarrow E = \frac{mv^2}{qR}$

]

Evaluating the Solution

$E = \frac{mv^2}{qR}$ } don't know m

$\Rightarrow$ use CO 28 g/mol

we will arbitrarily use 1 mol of substance:

$$\frac{28\,g}{mol} \cdot \frac{1\,mol}{1} \cdot \frac{1\,kg}{1000\,g} = 0.028\,kg$$

$\Rightarrow$ $E = \frac{mv^2}{qR}$

m = 0.028 kg
v = 8×10^4 m/s
q = -1.602×10^{-19} C
R = 0.8 m

$$E = \frac{(0.028\,kg)(8 \times 10^4 \frac{m}{s})^2}{(-1.602 \times 10^{-19}\,C)(0.8\,m)} = -1.398 \times 10^{27} \frac{N}{C}$$

implies $\vec{E}$ field is inverted

$\Rightarrow$ $\vec{E}$ direction must be downward

$\vec{E}$ direction: downward

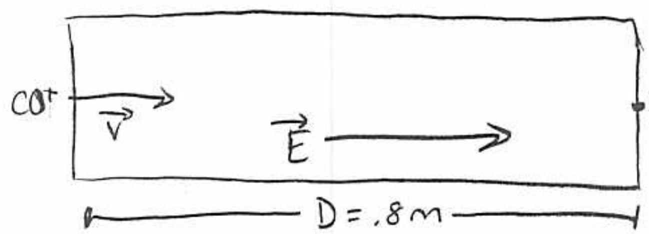
E magnitude: $1.398 \times 10^{27} \frac{N}{C}$

Checking the Answer

units:

$E = \frac{N}{C}$ $\Rightarrow$ $E = \frac{kg \cdot \frac{m^2}{s^2}}{C \cdot m} = \frac{N \cdot \cancel{m}}{C \cdot \cancel{m}} = \frac{N}{C}$ ✓

H



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

$V_i = 0$

$V_f = 8E4\ m/s$

$\Sigma F = F_E = ma$

$F_E = Eq$

Q: Calculate direction & magnitude of Electric field.

Approach/Solve:

Because CO^+ is a positive charge, the electric field will be moving in the direction of CO^+.

To find magnitude of E:

$m_{CO^+} = 28g = .028\,kg$

$\Sigma F = F_e = ma$

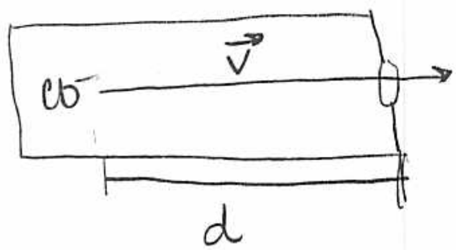
$v_f^2 = \cancel{v_i^2}^{\,0} + 2a\Delta x$

$v_f^2 = 2aD$

$a = \frac{v_f^2}{2D} = \frac{(8E4\frac{m}{s})^2}{2(.8m)} = 50{,}000\frac{m}{s^2}$

$F_e = ma = .028\,kg \times 50{,}000\frac{m}{s^2} = 1400 = Eq$

$E = \frac{1400}{q}$



Question: Find the direction and magnitude of the electric field needed to move the CO molecules through the hole at 8×10^4 m/s

$d = .8$ m
$\vec{v} = 8 \times 10^4$ m/s

Approach: use conservation of energy
assume gravity to be negligible in comparison to electric force

System: CO^+, box, Earth

t_i = when CO^+ molecule is at rest

t_f = when CO^+ molecule is leaving the box

$E_i = -\int \vec{F} \cdot d\vec{s}$

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

$E_{input} = q_0\vec{E}$

$E_{output} = 0$

Quantitative Relationships

$\vec{E} = \dfrac{\vec{F}}{q_0}$ $\quad PE = -\int \vec{F} \cdot d\vec{s}$ $\quad E_f - E_i = E_{in} - E_{out}$

$KE = 1/2\,mv^2$

$\Sigma F = 0$

We want the velocity and field parallel to make this motion.

$$-\int \vec{F} \cdot d\vec{s} = -q\vec{E}d\cos 0° = -qEd$$

Now all that's left is

$$\frac{1}{2}mv^2 + q\vec{E}d = q_0\vec{E}$$

$$\frac{1}{2}mv^2 = q_0\vec{E}(1-d)$$

$$\vec{E} = \frac{\frac{1}{2}mv^2}{q(1-d)}$$

$$m_{CO^+} = 28\frac{g}{mol} \cdot \frac{mol}{6.022 \times 10^{23} ions}$$

$$m_{CO^+} = 4.65 \times 10^{-23}\ g/ion = 4.65 \times 10^{-2?}\ kg$$

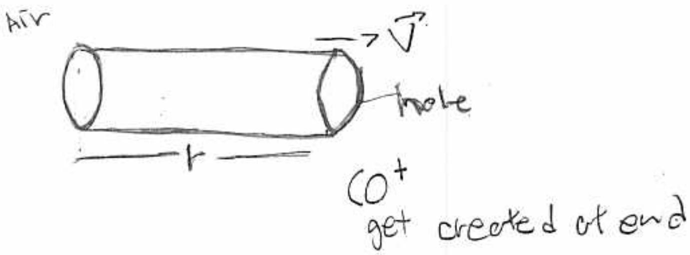
$q_0 = 1.602 \times 10^{-19}C$ because it has a +1 charge

$$\vec{E} = \frac{\frac{1}{2}(4.65 \times 10^{-20} kg)(8 \times 10^4 m/s)^2}{1.602 \times 10^{-19}C\ (1 - .8m)}$$

units $\frac{N}{C}$ ✓

$$\vec{E} = 4.64 \times 10^9\ N/C!$$

That is ridiculously high for the field but then again making a particle move from rest to 8,000 m/s in less than a meter is ridiculous too.



$V = 8\times10^4$ m/s
$r = 0.8$ m
$CO = 28$ g/mol

Question.

- Calculate the direction and magnitude of the electric field needed so that ions created at rest at one end will have a speed of 8×10^4 m/s when the exit the other side.

Approach

Use coulom's Law. to find out the magnitube of the electric field

Direction should be. right side

Solution.

$$F = K_e \frac{q_1 q_2}{r^2} \qquad K_e = 9.00\times10^9 \frac{N\cdot m^2}{C^2}$$

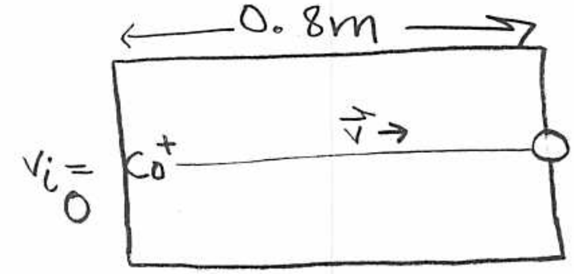
$$\vec{F} = q\vec{V}\times\vec{B}$$

F=

$$B = \frac{F}{q_1 V} = \frac{K_e q_1 \cancel{q_2}}{r^2}\cdot\frac{1}{\cancel{q_1} V} = \frac{K_e q_1}{r^2 \cdot V} = \frac{9.00\times10^9 \frac{N\cdot m^2}{C^2} \times 28\,g/mol}{0.64\,m^2 \cdot 8\times10^4\,m/s} = 4.92\times10^6 \frac{N\cdot g}{C^2\cdot m}$$

Unit ✓ kind of weird unit
answer ✓
reasonable?. ✓ yes

K



$s = 0.8$ m
$v_f = 8 \times 10^4$ m/s
$m_{CO} = 28$ g/mol

Question: Calculate the direction and magnitude of the electric field needed so that CO^+ ions created at rest at one end will have a speed of 8×10^4 m/s when they exit the other side

Approach: Use conservation of energy

system: Co^+ particle

intial time: right as CO^+ enters the box

final time: right as CO^+ leaves the box

$E_i = 0 \qquad v_i = 0$

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

E_{in} = electric potential energy

$E_{out} = 0$

Electric potential energy $= \Delta V q = -q \int \vec{E} \cdot ds$

because the electric field is constant

$PE_e = -qE \int ds$

$PE_e = -qES$ ← just want magnitude so can leave negative sign off

$E_f - E_i = E_{in} - E_{out}$

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

$E = \dfrac{\frac{1}{2}mv^2}{qs}$

check units

$\frac{1}{2}mv^2 \rightarrow$ energy units

$\underbrace{E \cdot s}_{V} \cdot \underbrace{q}_{C}$ = energy units

units ok ✓

$$|E| = \frac{\frac{1}{2}mv^2}{qs} = \qquad J = n \cdot m$$

$$CO - e^- = CO^+$$

$$.028\ Kg - 9.11 \times 10^{-31}\ Kg = 0.028\ Kg$$

$$|E| = \frac{\frac{1}{2}(0.028\ Kg)(8 \times 10^4\ m/s)^2}{(1.602 \times 10^{-19}\ C)(0.8\ m)}$$

$$\boxed{|E| = 6.99 \times 10^{26}\ N/C}$$

units ✓

$$\frac{Kg \cdot m^2/s^2}{C \cdot \cancel{m}} = N/C$$

<u>evaluate</u>

✓ units OK

✓ seems like a rather large magnitude for an electric field but it would make sense because it takes a lot to accelerate a CO^+ particle from rest to 8×10^4 m/s in such a short distance

The Electric field should be pointing right because it is the only force on the CO^+ particle and since the particle is being accelerated to the right, the force should be to the right.

PART II (To be done during the class):

6. Read scored example solution A and discuss the score of each category. These scores represent an evaluation of the student's strength in that area and should not be confused with grading. Discuss the basis on which the evaluator might have justified each score. Discuss within your group whether or not the scores give you a picture of the strengths of the student in solving this problem. Discuss how the scores could give you an indication of where the student needs coaching. Repeat step 6 for example solutions B-E as time allows.

Note: Each of the scored example solutions **A-E** include rubric scores at the top and score comments in boxes distributed throughout the solutions. Some features of the scored example solutions **A-E** are:

> **A. Logical progression is good (the solution process is clear) but the application of physics is incorrect**
>
> **B. Physics approach and math calculations are unnecessary for this solver (NA – Solver)**
>
> **C. The solution is unfocused and does not progress to an answer**
>
> **D. Example of a score “1” in physics approach**
>
> **E. A description is unnecessary for this solver (NA-Solver)**

7. Look at student solution **F**. Individually use the rubric to <u>assign a separate score</u> of **0, 1, 2, 3, 4, 5, NA(Solver), or NA(Problem)** for each of the five categories. On the scoring sheet, record the scores for student solution **F** and any relevant notes. Do not get any help from other members of your group.
On the scoring sheet, record your scores for student solution F and any relevant notes. Refer back to the example scores **A-E** as necessary. Remember, these scores do not represent a grade and would not be added together to arrive at one. However, use this experience to revise your own grade for this student's solution (at the top of the scoring grid) if you think it is appropriate.

8. Answer the questions on the scoring sheet. Record comments and scoring difficulties on page 2 of the scoring sheet.

9. Repeat steps 7 and 8 for student solutions **G-K** as time allows.

10. The session will finish with a discussion of the extent to which an awareness of the features of problem solving such as those in the rubric can help you make both teaching and grading decisions.

Problem Solving Rubric

	5	4	3	2	1	0	NA(Problem)	NA(Solver)
USEFUL DESCRIPTION	**The description is useful, appropriate, and complete.**	**The description is useful but contains minor omissions or errors.**	**Parts of the description are not useful, missing, and/or contain errors.**	**Most of the description is not useful, missing, and/or contains errors.**	**The entire description is not useful and/or contains errors.**	**The solution does not include a description and it is necessary for this problem /solver.**	**A description is not necessary for this problem. (i.e., it is given in the problem statement)**	**A description is not necessary for this solver.**
PHYSICS APPROACH	**The physics approach is appropriate and complete.**	**The physics approach contains minor omissions or errors.**	**Some concepts and principles of the physics approach are missing and/or inappropriate.**	**Most of the physics approach is missing and/or inappropriate.**	**All of the chosen concepts and principles are inappropriate.**	**The solution does not indicate an approach, and it is necessary for this problem/ solver.**	**An explicit physics approach is not necessary for this problem. (i.e., it is given in the problem)**	**An explicit physics approach is not necessary for this solver.**
SPECIFIC APPLICATION OF PHYSICS	**The specific application of physics is appropriate and complete.**	**The specific application of physics contains minor omissions or errors.**	**Parts of the specific application of physics are missing and/or contain errors.**	**Most of the specific application of physics is missing and/or contains errors.**	**The entire specific application is inappropriate and/or contains errors.**	**The solution does not indicate an application of physics and it is necessary.**	**Specific application of physics is not necessary for this problem.**	**Specific application of physics is not necessary for this solver.**
MATHE-MATICAL PROCEDURES	**The mathematical procedures are appropriate and complete.**	**Appropriate mathematical procedures are used with minor omissions or errors.**	**Parts of the mathematical procedures are missing and/or contain errors.**	**Most of the mathematical procedures are missing and/or contain errors.**	**All mathematical procedures are inappropriate and/or contain errors.**	**There is no evidence of mathematical procedures, and they are necessary.**	**Mathematical procedures are not necessary for this problem or are very simple.**	**Mathematical procedures are not necessary for this solver.**
LOGICAL PROGRESSION	**The entire problem solution is clear, focused, and logically connected.**	**The solution is clear and focused with minor inconsistencies**	**Parts of the solution are unclear, unfocused, and/or inconsistent.**	**Most of the solution parts are unclear, unfocused, and/or inconsistent.**	**The entire solution is unclear, unfocused, and/or inconsistent.**	**There is no evidence of logical progression, and it is necessary.**	**Logical progression is not necessary for this problem. (i.e., one-step)**	**Logical progression is not necessary for this solver.**

Problem Solving Rubric

<u>Category Descriptions</u>:

Useful Description assesses a solver's skill at organizing information from the problem statement into an appropriate and useful representation that summarizes essential information symbolically and visually. The description is considered "useful" if it guides further steps in the solution process. A *problem description* could include restating known and unknown information, assigning appropriate symbols for quantities, stating a goal or target quantity, a visualization (sketch or picture), stating qualitative expectations, an abstracted physics diagram (force, energy, motion, momentum, ray, etc.), drawing a graph, stating a coordinate system, and choosing a system.

Physics Approach assesses a solver's skill at selecting appropriate physics concepts and principle(s) to use in solving the problem. Here the term *concept* is defined to be a general physics idea, such as the basic concept of "vector" or specific concepts of "momentum" and "average velocity". The term *principle* is defined to be a fundamental physics rule or law used to describe objects and their interactions, such as the law of conservation of energy, Newton's second law, or Ohm's law.

Specific Application of Physics assesses a solver's skill at applying the physics concepts and principles from their selected approach to the specific conditions in the problem. If necessary, the solver has set up specific equations for the problem that are consistent with the chosen approach. A *specific application of physics* could include a statement of definitions, relationships between the defined quantities, initial conditions, and assumptions or constraints in the problem (i.e., friction negligible, massless spring, massless pulley, inextensible string, etc.)

Mathematical Procedures assesses a solver's skill at following appropriate and correct mathematical rules and procedures during the solution execution. The term *mathematical procedures* refers to techniques that are employed to solve for target quantities from specific equations of physics, such as isolate and reduce strategies from algebra, substitution, use of the quadratic formula, or matrix operations. The term *mathematical rules* refers to conventions from mathematics, such as appropriate use of parentheses, square roots, and trigonometric identities. If the course instructor or researcher using the rubric expects a symbolic answer prior to numerical calculations, this could be considered an appropriate mathematical procedure.

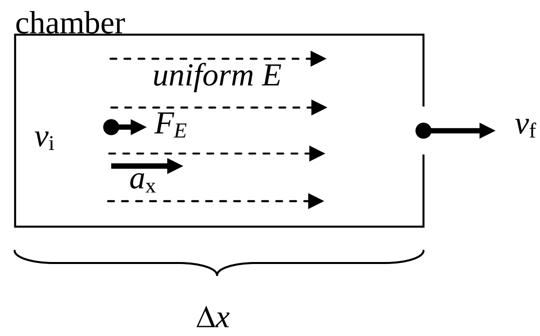
Logical Progression assesses the solver's skills at communicating reasoning, staying focused toward a goal, and evaluating the solution for consistency (implicitly or explicitly). It checks whether the entire problem solution is clear, focused, and organized logically. The term *logical* means that the solution is coherent (the solution order and solver's reasoning can be understood from what is written), internally consistent (parts do not contradict), and externally consistent (agrees with physics expectations).

Problem:

You are designing part of a machine to detect carbon monoxide (CO) molecules (28 g/mol) in a sample of air. In this part, ultraviolet light is used to produce singly charged ions (molecules with just one missing electron) from air molecules at one side of a chamber. A uniform electric field then accelerates these ions from rest through a distance of 0.8 m through a hole in the other side of the chamber. Your job is to calculate the direction and magnitude of the electric field needed so that CO^+ ions created at rest at one end will have a speed of 8×10^4 m/s when they exit the other side.

Example Instructor Solution:

Description



$v_i = 0$; initial velocity of the CO^+ molecule
$v_f = 8\text{x}10^4$m/s; final velocity of the CO^+ molecule
E: uniform electric field in the chamber
$\Delta x = 0.8$m; distance to hole in chamber
q = $1.602\text{x}10^{-19}$C; charge of a CO^+ molecule
m = mass of a CO^+ molecule
a_x= acceleration of the CO^+ molecule
F_E = force on the CO^+ molecule in the uniform electric field

Target: calculate the electric field, *E*

Solution Approach 1: Use Newton's Second Law to relate the force on the molecule to its acceleration; use kinematics to write an expression for acceleration in terms of velocity and distance. Assume gravity is negligible. Convert the mass of CO into kilograms per molecule.

$$\sum F_X = ma_X : \qquad qE = ma_X \qquad solve\ \ for\ the\ electric\ \ field:\ E = \frac{ma_X}{q}$$

$$v_f^2 = v_i^2 + 2a_X \Delta x \qquad solve\ \ for\ acceleration:\ a_X = \frac{v_f^2 - v_i^2}{2\Delta x}$$

$$m = \frac{28g}{mol} = \frac{0.028kg}{mol} \bullet \frac{1mol}{6.022\times 10^{23} molecules} \approx 4.65\times 10^{-26} kg/moleculeCO^+$$

$$E = \frac{m\left(v_f^2 - v_i^2\right)}{2q\Delta x} = \frac{4.65\times 10^{-26} kg\left(\left(8\times 10^4 m/s\right)^2 - 0\right)}{2\left(1.602\times 10^{-19} C\right)\left(0.8m\right)} = \boxed{1160\,N/C}\ direction\ is\ same\ as\ v\ (to\ the\ right.)$$

Solution Approach 2: Use conservation of energy to relate the electric potential energy transferred to the molecule and its final kinetic energy. Assume gravity is negligible. Convert the mass of CO into kilograms per molecule.

$$E_{final} - E_{initial} = E_{in} - E_{out} : \qquad \frac{1}{2}mv_f{}^2 - \frac{1}{2}mv_i{}^2 = q\Delta V - 0 \quad OR \quad \frac{1}{2}mv^2 - \frac{1}{2}mv_i{}^2 = \int \vec{F}\cdot d\vec{s} - 0$$

$$for\ uniform\ electric\ \ field:\ \Delta V = \int \vec{E}\cdot d\vec{s} = E\Delta x \qquad and \qquad \int \vec{F}\cdot d\vec{s} = F_E \Delta x = qE\Delta x$$

$$\frac{1}{2}mv_f{}^2 - \frac{1}{2}mv_i{}^2 = qE\Delta x\ \ solve\ \ for\ electric\ \ field$$

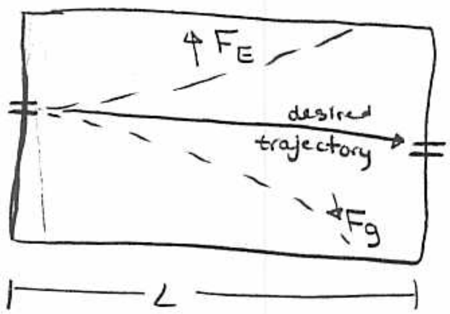
$$m = \frac{28g}{mol} = \frac{0.028kg}{mol} \bullet \frac{1mol}{6.022\times 10^{23} molecules} \approx 4.65\times 10^{-26} kg/molecule\ CO^+$$

$$E = \frac{m\left(v_f^2 - v_i^2\right)}{2q\Delta x} = \frac{4.65\times 10^{-26} kg\left(\left(8\times 10^4 m/s\right)^2 - 0\right)}{2\left(1.602\times 10^{-19} C\right)\left(0.8m\right)} = \boxed{1160\,N/C}\ direction\ is\ same\ as\ v\ (to\ the\ right.)$$

Check: The units are correct for electric field. We expect that for a particle with larger mass or higher final velocity the electric field would need to be stronger, which is consistent with the equation obtained.

F

picture:



$q = e$ $(= +1.602 \times 10^{-19}\ C)$

$v_i = 0\ m/s$

$v_f = 8 \times 10^4\ m/s$

$m = 28\ g/mol$

$L = 0.8\ m$

Question: What magnitude and direction of an electric field should be used for charged particles to reach a velocity of 8×10^4 m/s and experience no net force to make it through the hole on the other side?

Approach: Use Newton's Laws to find the value of $\vec{F}_E$ and then use that information to solve for $\vec{E}$.

$F_{total} = F_E + F_g = \emptyset \rightarrow F_g = |-F_E| \rightarrow mg = qE$

and $\vec{E} = \frac{\vec{F}_E}{q_0}$ $\quad \vec{F}_E = q\vec{E}$

$\boxed{E = \frac{mg}{q}}$

$F_g = mg \rightarrow m: \frac{28\ \cancel{g}}{\cancel{mol}\ CO} \cdot \frac{1\ \cancel{mol}}{6.02\times10^{23}\ molecule} \cdot \frac{1\ kg}{1000\ \cancel{g}} = 4.65\times10^{-26}\ kg/molecule$

$F_g = (4.65\times10^{-26}\ kg)(9.8\ m/s^2) = 4.56\times10^{-25}\ N$

$4.56\times10^{-25}\ N = qE \rightarrow E = \frac{4.56\times10^{-25} N}{q} = \frac{4.56\times10^{-25}\ N}{1.602\times10^{-19}\ C}$

$\boxed{E = 2.85\times10^{-6}\ \frac{N}{C} \text{ straight upward}}$

check units: $\frac{N}{C}$ is correct for

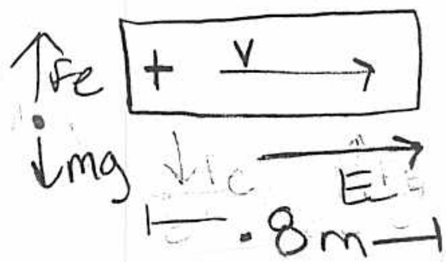
Useful Description:	**3**
Physics Approach:	**4**
Specific Application:	**2**
Math Procedures:	**5**
Logical Progression:	**4**

A

Description: direction of force inconsistent with direction of E-field and quantity "v" unclear

CO: 28 g/mol
UV light
E uniform
Q^+ $v = 8\times10^{14}$ m/s
.8m

picture:



Question: What is direction and magnitude of E?
approach: use Newton's laws to get force on particle and then use $F_e = qE$ to get E

plan solution

$\Sigma F = ma$

$\Sigma F_y = F_e - mg$

$F_e = qE$

Approach: Newton's second law written for y-direction but missing x-direction

Specific Application: incorrect force term in Newton's second law (gravity negligible), assumes no acceleration, and missing molar mass conversion

$qE - mg = 0$

$qE = mg$

$E = \frac{mg}{q}$

execute plan:

$$E = \frac{(.028\,kg)(9.8\,m/s^2)}{(1.602\times10^{-19}\,C)} = 1.71\times10^{18}\ N/C$$

evaluate answer:

reasonable? yes b/c a large electric field is needed to move a molecule of CO .8m

answer Q? yes → direction of E shown in picture

✓ units ✓

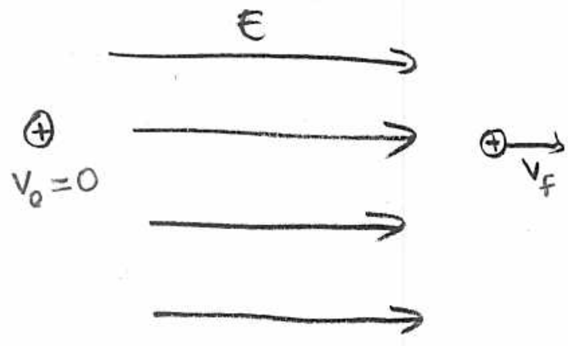
Logic: solution process is understandable but final answer unreasonably high

✓ units:

$kg\,\frac{m}{s^2} \to N$ $\frac{N}{}$

Useful Description:	5
Physics Approach:	NA(S)
Specific Application:	5
Math Procedures:	NA(S)
Logical Progression:	5

B



$\Delta x = 0.8\,m$

$V_0 = 0$

$V_f = 8 \times 10^4\ m/s$

Description: assigns appropriate symbols for quantities

$m = 28\ g/mol$

$$\frac{28\,g}{1\,\cancel{mol}} \left| \frac{1\,\cancel{mol}}{6.022 \times 10^{23}\,\text{atoms}} \right| \frac{1\,kg}{1000\,g} =$$

$m = 4.65 \times 10^{-26}\ kg$

Question: Find E field so that $V_f = 8 \times 10^4\ m/s$.

$\vec{E}$ field points in the same direction as desired velocity (can ignore gravitational force)

$+ \xrightarrow[F_e]{} \quad qE = F_e = ma$

Approach: general equations unnecessary for this solver (NA)

$$E = \frac{ma}{q} \qquad V_f^2 = \cancel{V_0^2}^{\,0} + 2a\Delta x$$

$$a = \frac{V_f^2}{2\Delta x}$$

$$E = \frac{m V_f^2}{q\, 2\Delta x} \equiv \frac{[kg]\cdot[m]^{\cancel{2}}}{[s]^2\,[C]\,[\cancel{m}]} = \frac{N}{C} \qquad \frac{V}{m} = \frac{N}{C} \qquad N = \frac{kg\,m}{s^2}$$

units ok ✓

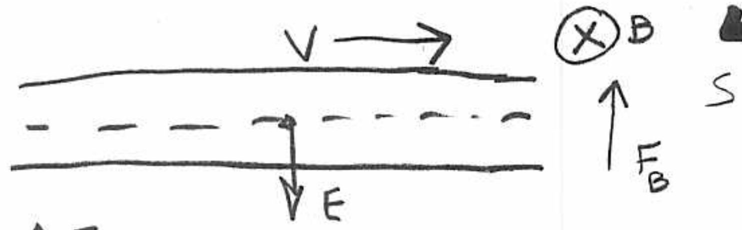
$$\boxed{E = 1162\ \frac{N}{C}}$$

Math: numerical calculations are not shown but the answer is correct (unnecessary step for this solver)

C

Useful Description:	2
Physics Approach:	3
Specific Application:	2
Math Procedures:	3
Logical Progression:	2

Description: direction of E-field incorrect and "v" unclear; incorrectly assumes there is an external magnetic field present



Knowns

$CO = 28 \frac{grams}{mol}$

$d = 0.8m$

$V = 8 \times 10^4 \frac{m}{s}$

$F_{net} = 0$ $\quad F = ma$

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

$F_B + F_E = 0$

$F_B = qV \times B$

$F_E = qE$

Approach: parts of the approach are missing (connection between forces approach and kinematics / accelerated motion)

$F_B - F_E = 0$, $V \perp E$ so,

$F_B = F_E$

$F_E = qVB$

$qVB - qE = 0$

Specific Application: incorrect force term in Newton's second law (B-field), assumes no acceleration, and missing molar mass conversion

$qVB = qE$

solve for B, q cancels and your left w/

Math: math procedures are missing (unfinished), and some are unused

$\vec{B} = \frac{\cancel{q} E}{\cancel{q} V} \Rightarrow B = \frac{E}{V} = \frac{E}{8 \times 10^4 \frac{m}{s}}$

$\frac{\Delta V}{\Delta t}$ $\quad V = \frac{d}{t} = \frac{0.8m}{t}$

$a = \frac{V}{t}$ $\quad V = at$

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

$KE = \frac{1}{2}(28g)(8 \times 10^4 \frac{m}{s})^2$

$KE = 8.96 \times 10^{1}$

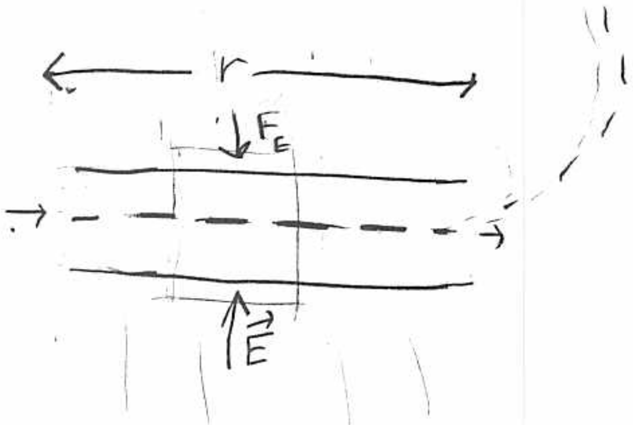
$t = \frac{0.8m}{8 \times 10^4 m/s} = 1 \times 10^{-5} \frac{m}{s}$

Logical Progression: Solution unfocused and contains some unit inconsistencies; doesn't progress to an answer for E-field.

Useful Description:	2
Physics Approach:	1
Specific Application:	2
Math Procedures:	5
Logical Progression:	2

D

<u>Description</u>: direction of E-field incorrect and "v" unclear; circular motion path incorrect



Knowns

CO molecules = 28g/mol

V = 8x10⁴ m/s

q = 1.602x10⁻¹⁹

r = 0.8m

useful equations

$\vec{E} = \frac{\vec{F}}{q_0} \Rightarrow F_E = q\vec{E}$

<u>Specific Application</u>: one force term is appropriate, but the rest of the application is incorrect

would travel in circle w/ radius r

& will be constant through 'plates'

$\vec{F} = \frac{V^2}{r}$

$= \frac{(8 \times 10^4 \, m/s)^2}{0.8m}$

$F = 8.0 \times 10^9$

<u>Approach</u>: equations indicate basic misunderstanding of Newton's second law

$\vec{E} = \frac{8.0 \times 10^9}{1.602 \times 10^{-19}} = \boxed{4.99 \times 10^{28}}$

<u>Math</u>: the math procedures are appropriate and complete for this student's physics approach

<u>Logical Progression</u>: most units are inconsistent or missing; the answer is unreasonable

E

Useful Description:	**NA(S)**
Physics Approach:	**5**
Specific Application:	**5**
Math Procedures:	**4**
Logical Progression:	**4**

Question: what is the direction and magnitude of an Electric Field is required to move a positively charged $CO^{\oplus}$ ion from rest to a velocity of 8×10^4 m/s in a distance of .8 m.

Description: description is missing but solution process correct, so unnecessary (NA-Solver)

Direction of E = $\longrightarrow$ in the direction of motion. (the direction of the force on the positively charged ion)

Approach: Use conservation of Energy (system defined as everything in the box)

$E_F - E_i = E_{in} - E_{out}$

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

E_i = Electric potential energy = $\Delta V \cdot q$

$\Delta V = -\int E \cdot ds$ (assume we are applying a constant E)

$= E \cdot d$

$E_{in} = 0$

$E_{out} = 0$

Logical Progression: reasoning for unit conversion value is missing

$E_F = E_i$

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

$\frac{2mv^2}{dq} = E$

$$\frac{2\,(4.65\times10^{-26}\,kg)(8\times10^4\,m/s)^2}{(.8m)(1.6\cdot10^{-19}C)} = \boxed{4650\ N/}$$

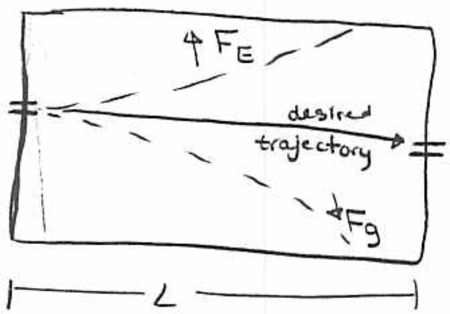
unit check

$\frac{kg\,m^2/s^2}{m \cdot C} = N/C$ ✓checks out

units of E = N/C

big but reasonable considering the high velocity it must obtain

Math: minor algebra mistake (factor of 2) when solving for E picture:



$q = e$ $(= +1.602 \times 10^{-19}\,C)$
$v_i = 0\ m/s$
$v_f = 8 \times 10^4\ m/s$
$m = 28\ g/mol$
$L = 0.8\ m$

Question: What magnitude and direction of an electric field should be used for charged particles to reach a velocity of 8×10^4 m/s and experience no net force to make it through the hole on the other side?

Approach: Use Newton's Laws to find the value of $\vec{F}_E$ and then use that information to solve for $\vec{E}$.

$F_{total} = F_E + F_g = 0 \rightarrow F_g = |-F_E| \longrightarrow mg = qE$

and $\vec{E} = \dfrac{\vec{F}_E}{q_0}$ $\quad \vec{F}_E = q\vec{E}$

$\boxed{E = \dfrac{mg}{q}}$

$F_g = mg \rightarrow m: \dfrac{28\ \cancel{g}}{\cancel{mol}\ CO} \cdot \dfrac{1\ \cancel{mol}}{6.02 \times 10^{23}\ molecule} \cdot \dfrac{1\ kg}{1000\ \cancel{g}} = 4.65 \times 10^{-26}\ kg/molecule$

$F_g = (4.65 \times 10^{-26}\ kg)(9.8\ m/s^2) = 4.56 \times 10^{-25}\ N$

$4.56 \times 10^{-25}\ N = qE \rightarrow E = \dfrac{4.56 \times 10^{-25}\ N}{q} = \dfrac{4.56 \times 10^{-25}\ N}{1.602 \times 10^{-19}\ C}$

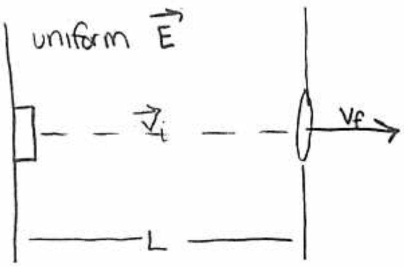
$\boxed{E = 2.85 \times 10^{-6}\ \frac{N}{C} \text{ straight upward}}$

check units: $\frac{N}{C}$ is correct for

G

Focus the Problem

Diagram:



$v_f = 8 \times 10^4$ m/s

$L = 0.8$ m

Question:

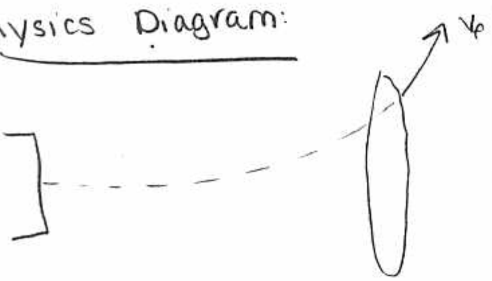
What is the direction & magnitude of the electric field such that the final velocity of the ion is 8×10^4 m/s?

Approach:

use $\vec{E} = \frac{\vec{F}}{q_0}$, dynamics, Newton's Laws $(F=ma)$, & kinematics to determine $\vec{E}$ field; find magnitude 1st then decide direction

Planning the Solution:

Physics Diagram:



$\vec{E} = \frac{\vec{F}}{q_0}$ $\quad F = ma \quad$ $a = \frac{v^2}{R}$

$E_f - E_{in} = 0$

$\Rightarrow E_f = E_i$

Solving the Problem:

① $a = \frac{v^2}{R}$ } know all but a

② plug ① into $F = ma$

$\Rightarrow F = \frac{mv^2}{R}$

③ $E = \frac{F}{q}$

$\Rightarrow E = \frac{mv^2}{qR}$

]

Evaluating the Solution

$E = \frac{mv^2}{qR}$ } don't know m

$\Rightarrow$ use CO 28 g/mol

we will arbitrarily use 1 mol of substance:

$$\frac{28\ g}{mol} \cdot \frac{1\ mol}{1} \cdot \frac{1\ kg}{1000\ g} = 0.028\ kg$$

$$\Rightarrow E = \frac{mv^2}{qR}$$

$m = 0.028\ kg$
$v = 8 \times 10^4\ m/s$
$q = -1.602 \times 10^{-19}\ C$
$R = 0.8\ m$

$$E = \frac{(0.028\ kg)(8 \times 10^4\ \frac{m}{s})^2}{(-1.602 \times 10^{-19}\ C)(0.8\ m)} = -1.398 \times 10^{27}\ \frac{N}{C}$$

implies $\vec{E}$ field is inverted

$\Rightarrow$ $\vec{E}$ direction must be downward

$\vec{E}$ direction: downward

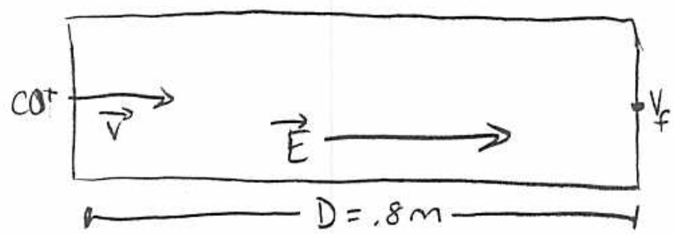
E magnitude: $1.398 \times 10^{27}\ \frac{N}{C}$

Checking the Answer

units:

$$E = \frac{N}{C} \Rightarrow E = \frac{kg \cdot \frac{m^2}{s^2}}{C \cdot m} = \frac{N \cdot \cancel{m}}{C \cdot \cancel{m}} = \frac{N}{C}\ \checkmark$$

H



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

$v_i = 0$

$v_f = 8E4\ m/s$

$\Sigma F = F_E = ma$

$F_E = Eq$

Q: Calculate direction & magnitude of Electric field.

Approach/Solve:

Because CO^+ is a positive charge, the electric field will be moving in the direction of CO^+.

To find magnitude of E:

$m_{CO^+} = 28g = .028\,kg$

$$\Sigma F = F_e = ma$$

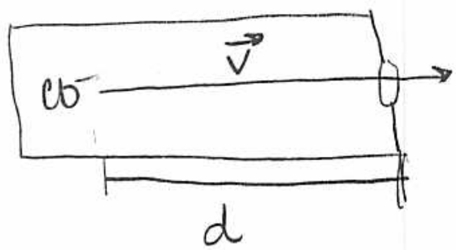
$$v_f^2 = \cancel{v_i^2}^{\,0} + 2a\Delta x$$

$$v_f^2 = 2aD$$

$$a = \frac{v_f^2}{2D} = \frac{(8E4 \frac{m}{s})^2}{2(.8m)} = 50{,}000 \frac{m}{s^2}$$

$$F_e = ma = .028\,kg \times 50{,}000 \frac{m}{s^2} = 1400 = Eq$$

$$E = \frac{1400}{q}$$



Question: Find the direction and magnitude of the electric field needed to move the CO molecules through the hole at 8×10^4 m/s

$d = .8$ m
$\vec{v} = 8 \times 10^4$ m/s

Approach: use conservation of energy assume gravity to be negligible in comparison to electric force

System: CO^+, box, Earth

t_i = when CO^+ molecule is at rest
t_f = when CO^+ molecule is leaving the box
$E_i = -\int \vec{F} \cdot d\vec{s}$
$E_f = \frac{1}{2}mv^2$
$E_{input} = q_0 \vec{E}$
$E_{output} = 0$

Quantitative Relationships

$\vec{E} = \frac{\vec{F}}{q_0}$ $\quad PE = -\int \vec{F} \cdot d\vec{s}$ $\quad E_f - E_i = E_{in} - E_{out}$

$KE = 1/2\, mv^2$

$\Sigma F = 0$

We want the velocity and field parallel to make this motion.

$$-\int \vec{F} \cdot d\vec{s} = -q\vec{E}d\cos 0° = -q\vec{E}d$$

Now all that's left is

$$\frac{1}{2}mv^2 + q\vec{E}d = q_0\vec{E}$$

$$m_{CO^+} = 28\frac{g}{mol} \cdot \frac{mol}{6.022 \times 10^{23} \text{ ions}}$$

$$\frac{1}{2}mv^2 = q_0\vec{E}(1-d)$$

$$\vec{E} = \frac{\frac{1}{2}mv^2}{q(1-d)}$$

$$m_{CO^+} = 4.65 \times 10^{-23} \text{ g/ion} = 4.65 \times 10^{-2?} \text{ kg}$$

$q_0 = 1.602 \times 10^{-19} C$ because it has a +1 charge

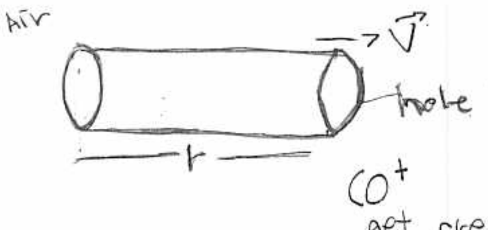
$$\vec{E} = \frac{\frac{1}{2}(4.65 \times 10^{-20} kg)(8 \times 10^4 m/s)^2}{1.602 \times 10^{-19} C \ (1 - .8m)}$$

units $\frac{N}{C}$ ✓

$$\vec{E} = 4.64 \times 10^9 \text{ N/C !}$$

That is ridiculously high for the field but then again making a particle move from rest to 8,000 m/s in less than a meter is ridiculous too.

J



$V = 8\times10^4$ m/s
$r = 0.8$ m
CO = 28 g/mol

Question.

- Calculate the direction and magnitude of the electric field needed so that ions created at rest at one end will have a speed of 8×10^4 m/s when the exit the other side.

Approach

Use coulom's Law. to find out the magnitube of the electric field

Direction should be. right side

Solution.

$$F = K_e \frac{q_1 q_2}{r^2} \qquad K_e = 9.00\times10^9 \frac{N\cdot m^2}{C^2}$$

$$\vec{F} = q\vec{V}\times\vec{B}$$

F=

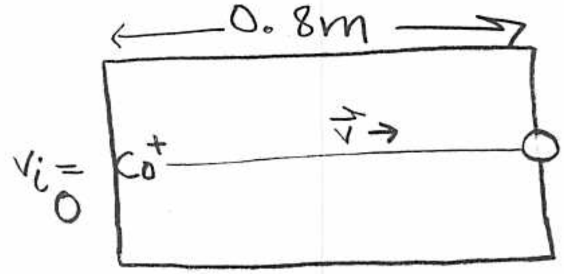
$$B = \frac{F}{qV} = \frac{K_e q_1 q_2}{r^2}\cdot\frac{1}{q_2 V} = \frac{K_e q_1}{r^2\cdot V} = \frac{9.00\times10^9 \frac{N\cdot m^2}{C^2} \times 28\,g/mol}{0.64\,m^2 \cdot 8\times10^4\,m/s} = 4.92\times10^6 \frac{N\cdot g}{C^2\cdot m}$$

Unit ✓ kind of weird unit

answer ✓

reasonable? ✓ yes

K



$s = 0.8$ m
$v_f = 8 \times 10^4$ m/s
$m_{CO} = 28$ g/mol

Question: Calculate the direction and magnitude of the electric field needed so that CO^+ ions created at rest at one end will have a speed of 8×10^4 m/s when they exit the other side

Approach: Use conservation of energy

system: Co^+ particle

intial time: right as CO^+ enters the box

final time: right as CO^+ leaves the box

$E_i = 0 \quad v_i = 0$

$E_f = \frac{1}{2}mv^2$ $\qquad$ E_{in} = electric potential energy

$E_{out} = 0$

Electric potential energy $= \Delta V q = -q\int \vec{E} \cdot ds$

because the electric field is constant

$PE_e = -qE\int ds$

$PE_e = -qES$ ← just want magnitude so can leave negative sign off

$E_f - E_i = E_{in} - E_{out}$ $\qquad$ <u>check units</u>

$\frac{1}{2}mv^2 = qEs$ $\qquad$ $\frac{1}{2}mv^2 \rightarrow$ energy units

$E = \dfrac{\frac{1}{2}mv^2}{qs}$ $\qquad$ $\underbrace{E \cdot s}_{V} \cdot \underbrace{q}_{C}$ = energy units

units ok ✓

$$|E| = \frac{\frac{1}{2}mv^2}{qs} = \qquad J = n \cdot m$$

$CO - e^- = CO^+$

$.028\,Kg - 9.11 \times 10^{-31}\,Kg = 0.028\,Kg$

$$|E| = \frac{\frac{1}{2}(0.028\,Kg)(8 \times 10^4\,m/s)^2}{(1.602 \times 10^{-19}\,c)(0.8\,m)}$$

$$\boxed{|E| = 6.99 \times 10^{26}\ N/C}$$

units ✓

$$\frac{Kg \cdot m^{\cancel{2}}/s^2}{C \cdot \cancel{m}} = N/C$$

evaluate

✓ units ok

✓ seems like a rather large magnitude for an electric field but it would make sense because it takes a lot to accelerate a Co^+ particle from rest to 8×10^4 m/s in such a short distance

The Electric field should be pointing right because it is the only force on the Co^+ particle and since the particle is being accelerated to the right, the force should be to the right.

Student F	Initial Grade:		Revised Grade:	
Rubric Part	**Score**	**Notes**		
Useful Description				
Physics Approach				
Specific App. of Physics				
Mathematical Procedures				
Logical Progression				

Student G	Initial Grade:		Revised Grade:	
Rubric Part	**Score**	**Notes**		
Useful Description				
Physics Approach				
Specific App. of Physics				
Mathematical Procedures				
Logical Progression				

Student H	Initial Grade:		Revised Grade:	
Rubric Part	**Score**	**Notes**		
Useful Description				
Physics Approach				
Specific App. of Physics				
Mathematical Procedures				
Logical Progression				

Please write your name here:____

Student I	Initial Grade:		Revised Grade:	
Rubric Part	**Score**	**Notes**		
Useful Description				
Physics Approach				
Specific App. of Physics				
Mathematical Procedures				
Logical Progression				

Student J	Initial Grade:		Revised Grade:	
Rubric Part	**Score**	**Notes**		
Useful Description				
Physics Approach				
Specific App. of Physics				
Mathematical Procedures				
Logical Progression				

Student K	Initial Grade:		Revised Grade:	
Rubric Part	**Score**	**Notes**		
Useful Description				
Physics Approach				
Specific App. of Physics				
Mathematical Procedures				
Logical Progression				

Please write your name here:____

Please write your name here:____

Questions:

1. What features do you usually look for when grading a student exam paper? How does that compare with the rubric categories?

Comments about the rubric scoring activity:

2. What difficulties did you encounter during this activity?

    a. Difficulties understanding the scoring task

    b. Difficulties using the scoring rubric

Please write your name here:____

3. Additional comments: