2019

AP® CollegeBoard

# AP® Physics 1: Algebra-Based

## Sample Student Responses and Scoring Commentary

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# AP® PHYSICS
# 2019 SCORING GUIDELINES

## General Notes About 2019 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

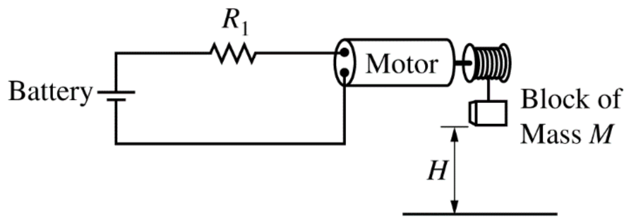
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.

5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but the use of $10 \text{ m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

## Question 4

**7 points**




A motor is a device that when connected to a battery converts electrical energy into mechanical energy. The motor shown above is used to lift a block of mass $M$ at constant speed from the ground to a height $H$ above the ground in a time interval $\Delta t$. The motor has constant resistance and is connected in series with a resistor of resistance $R_1$ and a battery.

Mechanical power, the rate at which mechanical work is done on the block, increases if the potential difference (voltage drop) between the two terminals of the motor increases.

(a) LO 5.B.5.5, SP 2.2
2 points

Determine an expression for the mechanical power in terms of $M$, $H$, $\Delta t$, and physical constants, as appropriate.

| | | |
|---|---|---|
| For an expression that implies reasoning in terms of energy (as opposed to e.g., kinematics) | | 1 point |
| Example: $MgH$ | | |
| For a correct expression for the power generated by the motor lifting the block at constant speed | | 1 point |
| $MgH/\Delta t$ | | |

(b) LO 5.B.9.2, SP 4.2, 6.4, 7.2; LO 5.B.9.3, SP 6.4, 7.2
5 points

Without $M$ or $H$ being changed, the time interval $\Delta t$ can be decreased by adding one resistor of resistance $R_2$, where $R_2 > R_1$, to the circuit shown above. How should the resistor of resistance $R_2$ be added to the circuit to decrease $\Delta t$ ?

___ In parallel with the battery ___ In parallel with $R_1$ ___ In parallel with the motor ___ In series with the battery, $R_1$, and the motor

In a clear, coherent, paragraph-length response that may also contain figures and/or equations, justify why your selection would decrease $\Delta t$.

| | | |
|---|---|---|
| Correct answer: "In parallel with $R_1$" | | |
| <u>Note:</u> If the wrong selection is made, the justification may still earn credit. | | |

## Question 4 (continued)

(b) (continued)

| | | |
|---|---|---|
| For a justification that correctly asserts that power must increase for $\Delta t$ to decrease, or correctly asserting that the faster the rate of energy transfer means that works gets done in a smaller time interval | | 1 point |
| For a correct assertion that current increases as resistance of the circuit decreases<br><br>*Alternate Method: Potential difference across the parallel resistors will decrease if their resistance decreases.* | | 1 point |
| For making the connection that there is an increase in current specifically in the motor because it is the same as the total current in the circuit<br><br>*Alternate Method: There is an increase in potential difference specifically across the motor because the potential difference across the parallel resistors decreases (Kirchhoff's loop rule).* | | 1 point |
| For a justification that indicates that connecting $R_2$ in parallel with $R_1$ will decrease the equivalent resistance of the circuit | | 1 point |
| For a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response | | 1 point |

| | | |
|---|---|---|
| Example Paragraph Response 1:<br><br>The work required to lift the block is *MgH*, so the rate at which the motor must do work to lift the block in the given time is $W/\Delta t = MgH/\Delta t$. The rate at which the motor does work increases with the potential difference across the motor (Note: This information is given in the question, so no points allotted in rubric for this statement.) To decrease the time, the motor must increase the rate at which the work is done, which requires a larger potential difference across the motor (or a larger current through the motor because $\Delta V = IR$ ). To increase the potential difference across the motor, the potential difference across $R_1$ must decrease, by Kirchhoff's loop rule (for a loop containing the battery, the motor and $R_1$ ). When $R_2$ is placed in parallel with $R_1$ the equivalent resistance of the combination decreases and the potential difference across that section decreases. | | |
| Example Paragraph Response 2:<br><br>Resistor $R_2$ should be connected in parallel with $R_1$. This will result in a smaller equivalent resistance in series with the battery and motor, so the current in the circuit (and through the motor) will be larger. The larger motor current results in the motor having a higher mechanical power. Because this power $MgH/\Delta t$ is larger and *MgH* is constant, the time interval $\Delta t$ will be smaller. | | |

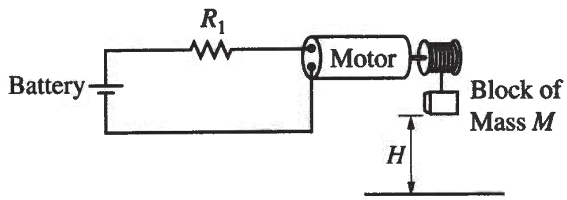
## Question 4 (continued)

**Learning Objectives**

**LO 5.B.5.5:** The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. [See Science Practices 2.2, 6.4]

**LO 5.B.9.2:** The student is able to apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule ($\Sigma\Delta V = 0$) in a circuit with only a battery and resistors either in series or in, at most, one pair of parallel branches. [See Science Practices 4.2, 6.4, 7.2]

**LO 5.B.9.3:** The student is able to apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch. [See Science Practices 2.2, 6.4, 7.2]




4. (7 points, suggested time 13 minutes)

A motor is a device that when connected to a battery converts electrical energy into mechanical energy. The motor shown above is used to lift a block of mass $M$ at constant speed from the ground to a height $H$ above the ground in a time interval $\Delta t$. The motor has constant resistance and is connected in series with a resistor of resistance $R_1$ and a battery.

Mechanical power, the rate at which mechanical work is done on the block, increases if the potential difference (voltage drop) between the two terminals of the motor increases.

(a) Determine an expression for the mechanical power in terms of $M$, $H$, $\Delta t$, and physical constants, as appropriate.

Mechanical Power $= \boxed{\frac{MgH}{\Delta t}}$ work = Fd

(b) Without $M$ or $H$ being changed, the time interval $\Delta t$ can be decreased by adding one resistor of resistance $R_2$, where $R_2 > R_1$, to the circuit shown above. How should the resistor of resistance $R_2$ be added to the circuit to decrease $\Delta t$?

___ In parallel with the battery ✓ In parallel with $R_1$ ___ In parallel with the motor ___ In series with the battery, $R_1$, and the motor

In a clear, coherent, paragraph-length response that may also contain figures and/or equations, justify why your selection would decrease $\Delta t$.

If $R_2$ is added in parallel with $R_1$, the total resistance of the circuit, excluding the motor, would be less than $R_1$ because the total resistance of a parallel circuit is less than the smallest resistor. According to Kirchoff's loop rule, the voltage drop across an entire circuit must equal zero. When $R_2$ is added in parallel with $R_1$, the voltage drop across that section decreases, which means the voltage drop across the motor must increase assuming the battery stays the same. Mechanical power increases because of this, so time must decrease assuming M and H are held constant.



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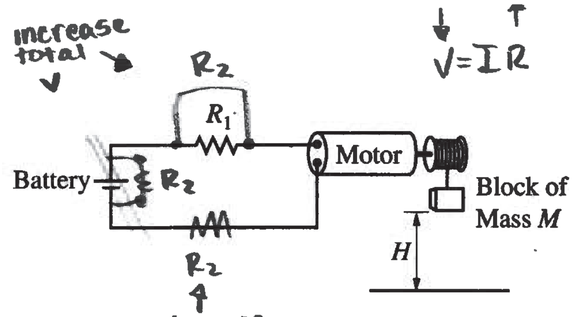
P1 Q4 B p1

$\downarrow$ $\uparrow$ $V = IR$




4. (7 points, suggested time 13 minutes)

A motor is a device that when connected to a battery converts electrical energy into mechanical energy. The motor shown above is used to lift a block of mass $M$ at constant speed from the ground to a height $H$ above the ground in a time interval $\Delta t$. The motor has constant resistance and is connected in series with a resistor of resistance $R_1$ and a battery.

Mechanical power, the rate at which mechanical work is done on the block, increases if the potential difference (voltage drop) between the two terminals of the motor increases.

(a) Determine an expression for the mechanical power in terms of $M$, $H$, $\Delta t$, and physical constants, as appropriate.

$P = \frac{W}{t}$

$W = \Delta E$

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

$E_i + W_{nc} = E_f$

$0 + W = mgh$

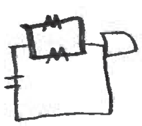
$W = MgH$

$P = \frac{MgH}{\Delta t}$

(b) Without $M$ or $H$ being changed, the time interval $\Delta t$ can be decreased by adding one resistor of resistance $R_2$, where $R_2 > R_1$, to the circuit shown above. How should the resistor of resistance $R_2$ be added to the circuit to decrease $\Delta t$ ?

___ In parallel with the battery  **X** In parallel with $R_1$  ___ In parallel with the motor  ___ In series with the battery, $R_1$, and the motor

In a clear, coherent, paragraph-length response that may also contain figures and/or equations, justify why your selection would decrease $\Delta t$.



$\uparrow V = IR \downarrow$

The power increases from a decrease in $\Delta T$, which occurs if the potential difference between the 2 terminals increases. Placing $R_1$ in parallel with $R_2$ would decrease the R of the overall circuit, as adding R in parallel decreases Resistance. This in turn would increase the V of the system, as the current is the same in series. This would increase voltage into the battery, decreasing $\Delta t$.



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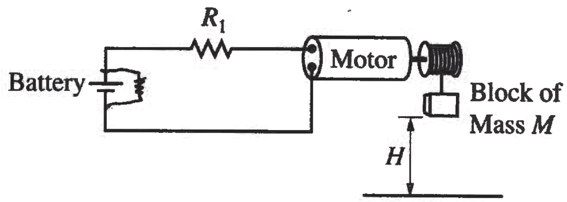


4. (7 points, suggested time 13 minutes)

A motor is a device that when connected to a battery converts electrical energy into mechanical energy. The motor shown above is used to lift a block of mass $M$ at constant speed from the ground to a height $H$ above the ground in a time interval $\Delta t$. The motor has constant resistance and is connected in series with a resistor of resistance $R_1$ and a battery.

Mechanical power, the rate at which mechanical work is done on the block, increases if the potential difference (voltage drop) between the two terminals of the motor increases.

$P=VI$
$=\frac{W}{t}=\frac{F \cdot d}{t}$

(a) Determine an expression for the mechanical power in terms of $M$, $H$, $\Delta t$, and physical constants, as appropriate.

$P=\frac{\Delta W}{\Delta t} \rightarrow \frac{F \cdot d}{\Delta t}$ ($F = m \cdot a$)   $\frac{(ma)(H)}{\Delta t}$ = mechanical Power

(b) Without $M$ or $H$ being changed, the time interval $\Delta t$ can be decreased by adding one resistor of resistance $R_2$, where $R_2 > R_1$, to the circuit shown above. How should the resistor of resistance $R_2$ be added to the circuit to decrease $\Delta t$ ?

___ In parallel with the battery   ✓ In parallel with $R_1$   ___ In parallel with the motor   ___ In series with the battery, $R_1$, and the motor

Voltage ↓

In a clear, coherent, paragraph-length response that may also contain figures and/or equations, justify why your selection would decrease $\Delta t$.

↑ ↓
$V=IR$

Putting $R_2$ in parallel with $R_1$ would main-tain the voltage, since Voltage stays the same in a parallel circuit, ~~and the current~~ and the current would be greater through $R_1$ since it has less resistance than $R_2$, and therefore the resistance would be less. Having the resistance ↓ and the voltage stay the same through the parallel would ensure that there would be less of a voltage drop ~~would~~ and would cause more Voltage to go through the motor thus decreasing the $\Delta t$.



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## Question 4

**Note:** Student samples are quoted verbatim and may contain spelling and grammatical errors.

**Overview**

This question provided students with a diagram of an electrical circuit with a resistor and a motor, with the motor lifting a block. Then it stated that the power of the motor is related to the voltage drop in the motor. Students were asked to demonstrate the following:

- Determine an expression for mechanical power using given variables. This required an understanding of energy and power, recognizing that the work done in lifting the block is equal to $MgH$, and that this quantity divided by time is the desired power.
- Explain, in paragraph form, how they would add another resistor to the circuit to decrease the time it took for the motor to lift the block. Students needed to recognize that lifting the block in a shorter time implies a greater power in the motor, meaning there must be a larger voltage drop in the motor. There were two common approaches to the responses. In one, the students explained that adding a resistor in parallel to $R_1$ would decrease the effective resistance of the circuit. This increases the current in the circuit, thus increasing the current in the motor, and by $V = IR$ increases the voltage drop in the motor. In the other approach, students recognized that adding a resistor in parallel to $R_1$ would decrease the resistance of that section of the circuit, which would cause a smaller voltage drop across $R_1$, meaning there would be a larger voltage drop across the motor according to Kirchhoff's loop rule. Students had to relate the increase in power or voltage drop of the motor to a shorter time to lift the block.
- In addition to showing understanding of how changes in the resistor arrangement would cause changes in current and voltage drop in the circuit, students had to provide an explanation in a logical, sequential and coherent format that eventually reached a result that indicated a decreased time to lift the block.

**Sample: 4A**
**Score: 7**

In part (a) both points were earned for using energy reasoning leading to a correct answer. For the paragraph-length response in part (b), all 5 points were earned. The response correctly relates a parallel arrangement of resistors to decreased equivalent resistance. Referencing Kirchhoff's loop rule, the response discusses potential difference (voltage drop) across the parallel section, resulting in an increased potential difference across the motor. The response then relates the increased power to decreased time. The response is a logical, relevant, and internally consistent argument that addresses the required argument.

**Sample: 4B**
**Score: 4**

In part (a) both points were earned for using energy reasoning leading to a correct answer. In part (b) 2 of 5 points were earned. One point was earned for relating increased power to decreased time, and 1 point was earned for correctly relating a parallel arrangement of resistors to decreased equivalent resistance. The response incorrectly concludes that "$V$ of the system" would increase and does not recognize the effect on potential difference in either the parallel resistor section or the motor. There is incorrect logic and reasoning in the response, as the statements that there is decreased resistance, the same current, and an increase in $V$ are not clearly connected and would seem to violate Ohm's law.

## Question 4 (continued)

**Sample: 4C**
**Score: 2**

In part (a) 1 of 2 points was earned for reasoning in terms of energy. One point was not earned because the expression for power is incorrect. The response incorrectly applies $F = ma$ in a work calculation rather than using potential energy. In part (b) 1 of 5 points was earned for connecting an increase in power to a decrease in time. The response explicitly connects more potential difference across the motor to the decrease in time, and the point was earned because the problem description notes the relation between mechanical power and potential difference across the motor. The remaining points in part (b) were not earned. Although there is a correct statement that resistance is less for a parallel resistor arrangement, there is incorrect reasoning used to justify this statement. While the response discusses changes in potential difference, there are contradictions in the explanation.