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Constant Acceleration
Model development

Class: AP Physics 1
Grade Level: 10-12
Estimated Time: 1 block (90 minutes)

Virginia SOLs:

- The student will plan and conduct investigations using experimental design and product design processes. (PH.1.b, c, d, f, g)
- The student will investigate and understand how to analyze and interpret data. (PH.2.b, d)
- The student will investigate and understand the interrelationships among mass, distance, force, and time through mathematical and experimental processes. (PH.5.a)

AP Physics 1 Standards: 3.A.1.1, 3.A.1.2, 3.A.1.3

Background knowledge: Students will already have operationally defined Constant Velocity, constructed the Constant Velocity Model, and completed several labs and activities using this model.

Student Learning Objectives for these activities:

1. To introduce photogates as a tool for experimentation and data collection.
2. To begin development of a Constant Acceleration Model with an emphasis on the relationship between acceleration, displacement, and time.

Students maintain a lab notebook as a requirement of this course, and it is expected that they are recording all discussions, whiteboarding and experimentation as described below.

Activity 1: Introduction to Photogates (30 minutes)

Materials needed: one large whiteboard per team, marble and steel track, meterstick, ruler and string (to measure marble diameter), two photogates, wooden track with CPO car

1. Students are given a marble, a steel track, and a photogate. Teacher asks them “What do the photogates measure?” and students are given a chance to play. (This is the warm-up as students walk in the room.)

2. Teacher interrupts play and ask students to whiteboard their responses to “What do the photogates measure?” and “For what purpose would you use photogates?” or “How would a photogate allow you to calculate velocity?

   Students circle up and show their whiteboards, discussing their responses with the class. Teacher scribes student response to the second question on the board:

   Anticipated Response:

   <u>One photogate: Calculate instantaneous velocity</u>
   1. *Measure diameter of marble (in meters).*
   2. *Send marble through photogate and record time to pass through.*
   3. *Diameter of marble (m) / time to pass through (s) = velocity (m/s)*

3. Teacher gives students a small CPO car* and a wooden track and asks them to measure velocity. Challenge to motivate students: “Who can get the slowest (or fastest?) time?” Students whiteboard how they measured the width of the car in diagrams in words and sketches, and show how they calculated velocity in words and numbers. Students share whiteboards with the class and discuss.

   *CPO car is tricky – the width of a vertical tab is what they need to actually measure, not the length of the car!

4. Teacher hands out a second photogate, asks students “How do you measure velocity with two photogates?” and allows students to play. Students verbally discuss their responses. Teacher scribes on board and students copy:

   <u>Two photogates: Calculate average velocity</u>
   1. *Measure separation distance between two photogates*
   2. *Send marble through photogates and record Δt between the gates*
   3. *Separation distance (m) / Time to travel separation distance (s) = velocity (m/s)*

5. Teacher asks students to compare one photogate versus two with prompt “What is similar and different between two measurements of velocity?” Teams discuss, whiteboard response, and share with class. Teacher adds “instantaneous” and “average” to the headings of the previous scribing (students should already be familiar with this vocabulary and may have missed this distinction earlier in the activity.)

Activity 2: Operation Definition of “Acceleration” (15 minutes)

(Note: As part of the construction of the Constant Velocity Model several lessons ago, students were given a marble and steel track and asked to create and define an operational definition for Constant Velocity.)

Materials needed: one large whiteboard per team, marble and steel track, meter stick, stopwatch

1. Students are given a marble and steel track. Teacher asks students “How do you create a situation with your marble and ramp where the Constant Velocity Model will NOT describe the motion.” Students do so and whiteboard a sketch and motion diagram, which they present to the class.

   Anticipated Response: Students take their marble and track and lift one end onto a stack of books.

2. Teacher asks class “How would you describe this motion if it is not Constant Velocity?”

   Anticipated Response: “Acceleration!”

3. Students are given a meter stick and stopwatch and asked to create an operational definition* for “Accelerated Motion.”

   *Students have done this for Constant Velocity and should know how to proceed. Teacher will circulate and provide targeted individual assistance.

4. Students will whiteboard their definitions and present to the class. Teacher will facilitate discussion as needed and scribe a class consensus on the board:

   Anticipated Response: Accelerated Motion is “increasingly more displacement in equal times” OR “increasingly less time in equal displacements”

Activity 3: Acceleration in terms of Displacement (45 minutes)

Materials needed: one large whiteboard per team, marble and steel track, two photogates, meterstick

1. Teacher asks class “How can we experimentally verify these definitions?” Teacher assigns first definition to half of class and second definition to second half of class. Class brainstorms in teams and writes a procedure on their whiteboard, then shares in a circle.

Anticipated response:

- *For first definition (regarding more displacements, equal times), students will try to place two photogates at several positions along so that the marble covers equal times between them.*
- *For second definition (regarding less times, equal displacements), students will equal displacements at several points along the track and use two photogates to measure the time that the marble takes to travel these displacements.*

2. Class will agree when asked that the second definition and procedure will be much easier and less time-consuming. Teacher asks teams to predict how they will use their data to verify the chosen definition and what the result will look like. Students whiteboard, present, and discuss.

   Anticipated response: Students will want to create a position-time graph and predict their line of best fit will have an exponential shape.

3. Students now perform their procedure, take data, and create their graph.

4. Post-game analysis questions when students present their results via whiteboard:
   - What do you notice about the slope on your non-linear line?
   - Which marble was the fastest and how can you tell? Slowest?
   - What form of equation would your line of best fit take? Think back to algebra…
   - Where is velocity on this graph?

Assessment

1. Formative Assessment:

Throughout all three activities, students will be discussing in small groups, whiteboarding, presenting, and reaching a class consensus. The teacher will be circulating among groups to listen to discussions and ask questions and will facilitate class discussions. Additionally, students record work in lab notebooks and on whiteboards which the teacher will review while circulating among groups. In particular, the teacher is looking to see that individual students

- understand the purpose of a photogate, are capable of using one, and can calculate velocity from the collected data (this will also be assessed with a quick quiz the following class.)
- understand the operational definition of accelerated motion and predict how this motion would appear on a position-time graph (this will also be assessed with a lab summary.)

2. Summative Assessment:

- Students write a summary of the lab (procedure, data, results and Model thus far) to submit the next class period.
- Students complete a quick quiz at the beginning of the following class (included at the end of the lesson) that asks the following questions:
  1. What were the results from the Photogate lab? Summarize two methods on how to use a photogate.
  2. Memory depends on having a rich context (build a detailed picture in your head). Describe a memory of the lab; explain how this image reminds you of the details in how to use a photogate to find velocity.

What Comes Next (in the development of this model):

Activity 4: Use position-time graph as an introduction to linearizing graphs and to construct equations of motion! We've done this already in CTA (year 1).

Activity 5: Students investigate the relationship between acceleration and velocity by constructing a velocity-time graph from their data. They will use this graph to identify the acceleration as "constant." To create the velocity-time graph, students have two options:

- Students will re-create their x-t graphs on software and use the tangent/slope to create a velocity-time graph (like we did in CTA year 1).
- Students can do a new experiment with their marble and steel track where they mark equal displacements from the top of track, use a single photogate to calculate instantaneous velocity at these positions, and create a velocity-time graph.

Students can complete either method, depending on their need for math practice or equipment practice, or they can complete both methods and compare the two graphs.