Names: **Date:** **Class:**

Pendulum Art Packet Answer Key

Instructions: You are an intern for a neurologist. It is time to interview your first patient! Fill out the patient intake form below.

Patient Intake Form

Patient Information

- **Full Name:** Jane Smith *(Answers will vary.)*
- **Date of Birth:** 5/15/2012 *(Answers will vary.)*
- **Emergency Contact Name:** John Smith *(Answers will vary.)*

Current State of Mind:

(Please check all that apply)

- Deep sleep
- Loss of bodily awareness
- Creative
- Deep meditation
- Reduced consciousness
- Awake and relaxed
- Excited
- Thinking
- Alert consciousness
- Ready to learn
- Heightened perception
- Other: _____

(Student answers will vary.)

Example answer:

☑ Creative

☑ Awake and relaxed

☑ Ready to learn

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Now that you have an idea of how your patient is feeling, identify what kind of brain waves you think they are currently experiencing. Since it is your first day on the job, your boss provided this graphic to help you predict brain waves. Circle the predicted brain wave. [Here is a quick video on EEGs](#).

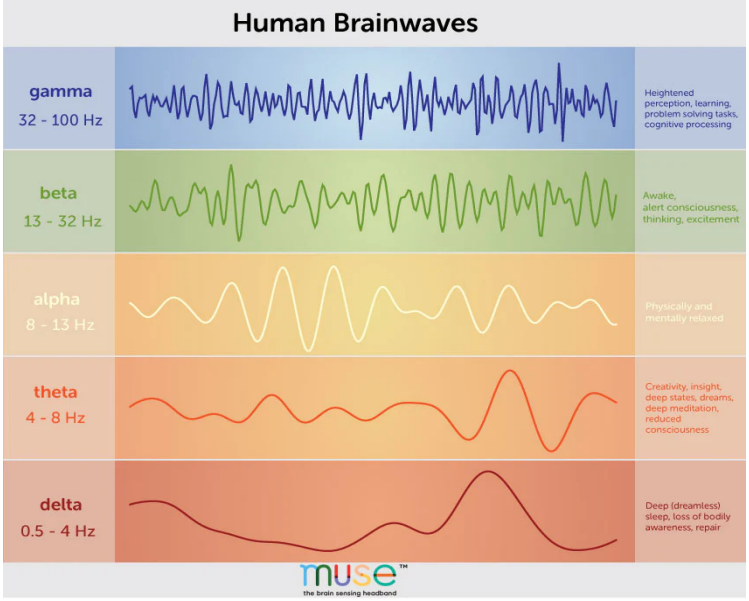

Image credit: https://choosemuse.com/blogs/news/a-deep-dive-into-brainwaves-brainwave-frequencies-explained-2

Example Answer for Awake and Relaxed
Predicted brain wave: Alpha waves

Other acceptable answers may include:

Patient State	**Brain Wave**
Deep sleep	Delta
Reduced consciousness	Theta
Deep meditation	Theta or Alpha
Creative	Alpha
Awake and relaxed	Alpha
Thinking	Beta
Alert consciousness	Beta
Excited	Beta
Heightened perception	Gamma

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Your patient needs a visual representation of what is going on in their brain. Design a pendulum to model the motion of their brainwaves.

Brain Wave Model Pendulum Design

Your pendulum will need to have a period in the range of the brain waves you are trying to model.

Type of brain wave: Answers will vary. For example, the above example: Alpha

Target Frequency: Answers will vary. For Alpha example: 10 Hz (Although any frequency within the selected brain wave range is acceptable.)

Using the relation between frequency and period, calculate.

Target period for the pendulum: Answers will vary, but accept answers consistent with the student's chosen frequency and scale factor. For the Alpha example:

Students use $T = 2\pi\sqrt{\frac{l}{g}}$

Rearranging, $l = g\left(\frac{T}{2\pi}\right)^2$

For $T = 0.10$ s and $l \approx 0.0025$ m

Because this is too short to build, students multiply by the activity scale factor.

Scaled length (×100): **≈ 0.25 m (25 cm)**

Remember, the period of a simple harmonic pendulum can be modeled by:

$\boldsymbol{T = 2\pi\sqrt{\frac{l}{g}}}$ where T is period, l is length of the pendulum, and g is acceleration due to gravity.

Design the pendulum. Think about which factor you can change to make your pendulum oscillate at the desired period. Draw a picture of your model pendulum and label the pendulum with the material you would use. Include your measurements.

Sketches will vary but should include the following features, labels, and measurements:

- pendulum
- cup
- string
- support
- labeled length
- materials

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Build the pendulum! Test it out. Answer the reflection questions below.

Reflect

Did you achieve your target period?
Example answers:
Yes. Our measured period was close to the calculated value.
or
No. Our pendulum swung slightly slower than expected.

Does the patient understand what is going on in their brain now?
Example answer:
Yes. While the pendulum does not represent actual brain activity, it provides a model that helps the patient understand how oscillating signals with different frequencies can be visualized and analyzed by biomedical engineers.

If you were to do it again, what would you change?
Possible answers:

- Measure the string more carefully.
- Make the pendulum shorter/longer.
- Use a different cup.
- Measure the period more accurately.
- Reduce friction.

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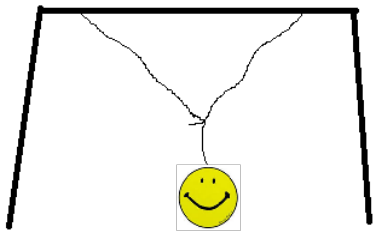
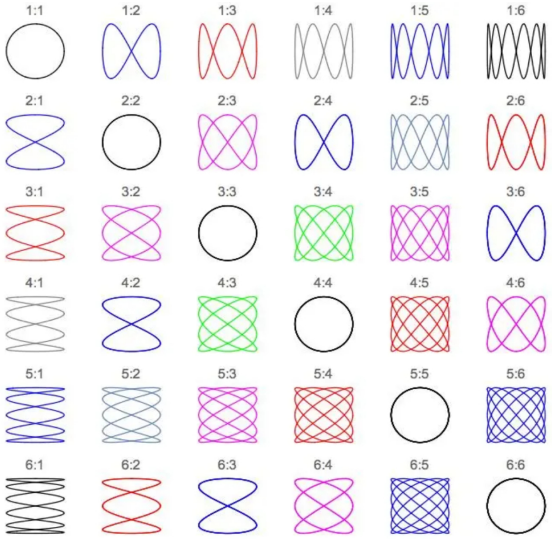
As an intern, you are trying to learn more about electroencephalography (EEG), a procedure used to measure brain activity. You know that comparing overlapping brainwave patterns can help researchers analyze EEG recordings. You decide to compare the brainwave patterns of two different patients by overlapping them. Find a patient in the room whose brainwave pattern is different from your patient's.

Planning: New Pendulum Design

Modified Pendulum





Lissajous Patterns

The numbers represent the ratio between the frequencies in the directions of oscillation. So, 1:1 means the periods in both directions are the same, and 1:2 means that the period in one direction is twice as long as the other.

How could you create a pendulum like the one in the image to the left and use it to model both oscillations?

- Target Frequency (f1):
  Target Frequency (f2):
- What property of the pendulum decides the frequency?
  The pendulum length.
- How could you have both of the lengths associated with the two frequencies incorporated into this design?
  Example answer:
  Use a pendulum that has two effective lengths so it can swing in two perpendicular directions with different periods.
- Your goal is to create a painting that matches one of the Lissajous patterns.
- Round off your frequencies, if necessary, to match one of the ratios in the pattern. Calculate the periods (T) and lengths (L) for oscillations corresponding to the rounded-off frequencies.
  Accept any mathematically correct solution.

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Improve
Were you successful in modeling your target frequencies? Does your picture look like the Lissajous pattern that you chose? Possible answers: • Yes, our pattern closely matched the target Lissajous pattern. • Partially. Our pattern was similar but not exact. • No. Our pendulum lengths or release angles need adjustment. If you were to redesign your pendulum, what would you do differently? Possible answers: • Adjust one pendulum length. • Change the release angle. • Improve paint consistency. • Measure more carefully. • Reduce friction.

Gallery Walk Reflection Questions

1. Is there a repeating pattern visible in the designs?
   Yes. The pendulums create repeating, periodic patterns.
2. Do the designs created by the new modified pendulums represent simple harmonic motion?
   No. Each individual direction undergoes simple harmonic motion, but the final two-dimensional motion is a combination of two simple harmonic motions.
3. Can you break the pattern down into the x and y components? [Hint: the two frequencies]
   Yes. The pattern is made from one oscillation in the x-direction and one oscillation in the y-direction.
4. What does the period depend on?
   For a simple pendulum, the period depends on pendulum length and acceleration due to gravity.
5. What kind of different patterns do you see around the room? List at least three similarities that you see and three differences that you see.

Reflect on the new pendulum	
Similarities Possible answers: • Repeating patterns • Smooth curves • Symmetry • Closed loops • Two-direction motion	Differences Possible answers • Different shapes • Different sizes • Different frequency ratios • Different amounts of symmetry • Different numbers of loops