Investigation: Wave Behaviours

Introduction

It’s hard to find a playground that doesn’t have a swing set and swinging is always heaps of fun. But what makes the swing go higher and faster? How can we push someone so that they swing higher and have a better time?



We know that when we push someone on a swing it is best to push them from when they are highest and on their way back down to the ground. But how often should you push them so that the person swinging goes as high as possible?

In this experiment, we will try to analyse the motions of a swing using a pendulum. This is a mechanical system and the pendulum is a harmonic oscillator. We will be measuring the natural frequency of a pendulum and determining the frequency of pushes that improve the swinging motion of the pendulum the most. We will also be considering the energy transformations of this system. Things to think about before the experiment: at what point of a swing do you think you are moving the fastest?

1. Questioning and predicting

So, let us think about the aim of this investigation.

1. What is the natural frequency the pendulum wishes to swing at?
2. What frequency of an added regular force increases the swinging motion the most?

HYPOTHESIS

The regular pushing force will be most effective at increasing the swinging motion at a frequency (that matches the natural swing/is fastest/is slowest)

2. Planning investigation

This investigation has been planned for you.

We will use one pendulum and find the frequency of pushes that naturally increases the amplitude of the swinging pendulum.

1. Set up your apparatus as shown in the picture below:
2. Place a 1 meter ruler horizontally against the wall. This will give you a scale for measuring the displacement of the object.
3. Use a smartphone or digital camera to record a video of the mass swinging from the time when it is released.
4. Raise one mass up a small angle and release it to let it swing.
5. The frame rate (in frames per second) of the recording is a fixed value which you can get from the camera settings. Find this value. Convert his to the time per frame. (For example, if the video is recorded at 30 fps, each frame lasts for 1/30th of a second.)
6. Look at the video frame by frame. What is the positon of your object against each ruler for each frame?
7. Record the object’s horizontal position and vertical position at each frame in the table on the next page. If there are a large number of frames, you may wish to take data every five or ten frames.
8. Repeat the experiment but ‘bump’ the mass at a consistent rate and force so that the pendulum keeps swinging smoothly and the amplitude of the pendulum increased. Make sure the hand is only moving in the horizontal direction.

Some groups may choose to download the free app ‘VidAnalysis Free’ for androids or the app ‘Vernier Video Physics’ for iPhones and analyse the video within the app to create graphs of the x-positions and y-positions over time.

3. Conducting investigation

For each pendulum, you should take a video that clearly shows the mass swinging and the scale of the ruler until the object hits the floor and the motion of the hand hitting the mass. Choose suitable time intervals and record the horizontal displacement of the mass and the horizontal displacement of the hand when applicable.

No input:

|  |  |  |
| --- | --- | --- |
| Time (s) | Horizontal Displacement (m) | Any other comments on motion of object and taking the video |
|  |  |  |

Input frequency:

Mass displacement:

|  |  |  |
| --- | --- | --- |
| Time (s) | Horizontal Displacement of mass (m) | Any other comments on motion of object and taking the video |
|  |  |  |

Hand displacement:

|  |  |  |
| --- | --- | --- |
| Time (s) | Horizontal Displacement of hand (m) | Any other comments on motion of object and taking the video |
|  |  |  |

**Did you make any changes to the method? Did you have design problems to solve? Did you have some ‘smart’ ways of doing the investigation?**

4. Processing and analysing

Plot the displacement of the mass versus time on graph paper or using a spreadsheet program for the horizontal displacement. Plot the displacement of the hand (when used) versus time as well.

What shape are each of the displacement-time graphs of the mass and the hand? What shape would you expect the velocity-time graphs to be (remember the velocity is the change in displacement over the change in time)?

Try plotting the velocity-time graph of the pendulum mass for two periods of oscillation.

Finding the frequency of oscillation requires us to know the period of the oscillation. Mark on your graph a point where the displacement in a maximum and record the value of the time at that point, then record the time at the next maximum point on the graph. What is the difference between those times? To improve the validity of this period, record the time it takes for your pendulum to complete 10 full oscillations. Using the formula,

$T=\frac{t}{10}$ ,

where $T$ is the period of one oscillation and $t$ is time for 10 full oscillations, calculate the time for one oscillation.

Repeat this for the input force of the hand too.

What shape do you expect the velocity-time plots to be for both the mass and the hand?

5. Problem solving

* Consider the energy transformations (always has constant mechanical energy, but the kinetic is max when position is zero and zero when still at max distance vice versa for the potential energy

This is the section where we think about the results and what they mean.

When we let the pendulum swing it has a periodic motion. Each pendulum has a natural frequency at which it wants to oscillate. We can calculate it using:

$$f=\frac{1}{T}$$

where f is the frequency and T is the period. The period is measured in seconds as the time for the pendulum to complete one oscillation (the time we measured in our analysis)

What was the natural frequency of the pendulum?

\_\_\_\_\_\_\_\_\_\_\_\_

What was the frequency of the optimal input force?

\_\_\_\_\_\_\_\_\_\_\_\_

What can you say about these two frequencies?

The **amplitude** of the pendulum is the maximum displacement of the mass during the oscillation.

The **natural frequency** of oscillation is the frequency your pendulum wishes to oscillate at. No matter how high you begin the oscillation at or how hard you push the mass at the beginning, it will always oscillate with this frequency.

The **driving frequency** of a harmonic oscillator is the frequency of the input force, how frequently you pushed the pendulum in this case.

What relationship did you observe between the driving frequency and the natural frequency which increased the amplitude of your pendulum?

6. Conclusions

The natural frequency of the pendulum was \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

The frequency of the driving force that increased the amplitude was \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

The total energy of the system stays the same and the kinetic and potential energies \_\_\_\_\_\_\_\_\_\_\_\_\_.