UVA's Hands-on Introduction to Nanoscience

Ripple Tank Labs: Guidelines & Reporting Form

(revision 11 February 2014)

Student Name (printed):__________________________________

Signature:________________________________

Lab Preparation:

a) Download and review the manual provided by the ripple tank's manufacturer, Pasco. The first ten pages of that manual provide general information on the equipment and its setup. The remaining pages suggest experiments for the ripple tank. Copies of this manufacturer's manual will be in the lab so you need not print it out.

b) Print out and **bring to the lab your own copy of THIS** Guidelines & Reporting Form.

Lab: Step 1) Configure the system as shown on the first page of the Pasco manual:

The rectangular LED light source bar is placed high on the rod which is screwed into the tank. Its LED hole should be over the approximate center of the tank, pointing downward.

The ripple generator (the electronics box) is on the separate rod / base. The generator should overhang the tank (but not quite touch it). It should be perpendicular to the tank with its center point at about the center of the tank's edge.

The LED light source should be plugged into the ripple generator, and the ripple generator plugged into an AC power source.

Step 2) Carefully level the tank using the spirit level we've added to the kit by adjusting the screw-in feet at the bases of the tank's three legs.

Step 3) Find the drain that hangs down from one corner of the tank, and figure out how to open and close it. Then close it.

Step 4) Fill the tank with ~ 800 ml of water

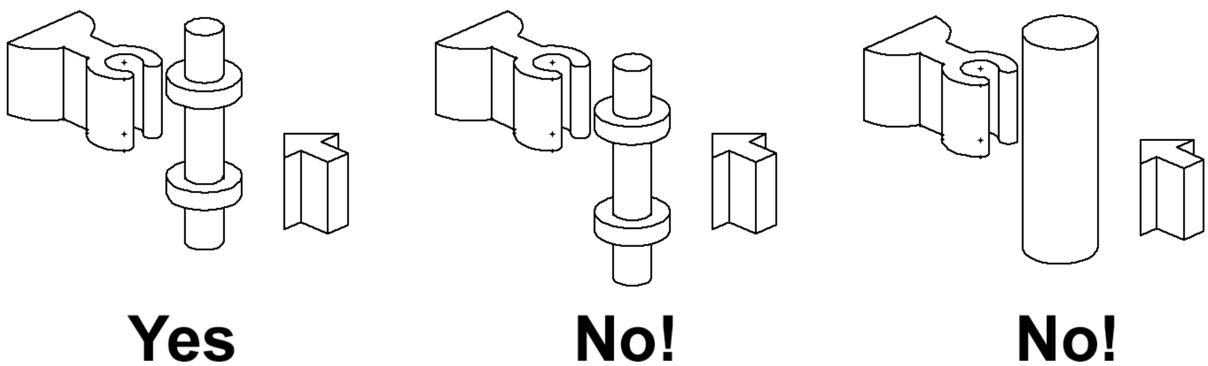
Step 5) To help water wet the foam bumpers, wipe them with a few drops of surfactant

Step 6) Place the now empty measuring cup under the tank drain, so that you can later adjust the water level in the tank

Experiment #0) Learn how to generate high quality "plane" (straight) waves

DON'T RUSH THIS "EXPERIMENT" – Getting really good at these steps will make it MUCH easier to do ALL of the experiments that follow!

Step 1) ATTACH the long "Plane Dipper" bar to the wave generator (item 1, page 7 of the Pasco manual). Its two rods snap into the sockets on the generator unit. But only the narrowest parts of these black plastic rods fit inside the socket - do NOT force the ridges (or metal rods on other parts) into these sockets:



Step 2) ALIGN the generator so the "plane dipper" bar is parallel to the tank's edge, and about 5 cm (2") out from the foam bumper (use the ruler to even up the separation of the bar from the tank's edge to within ~ 1mm end to end).

Step 3) LEVEL THE DIPPER: Using the two red knobs on the generator box, lower the bar so that it just touches the water along its whole length. Most likely this will require adjusting the tilt of the generator using the tilt red knob (the one in the corner of the generator box) – see the manual page 8. Repeatedly use the lift red knob, lifting then lowering the bar out of the water until you are sure that it is contacting the water all along its whole edge simultaneously.

Step 4) SET THE DIPPER'S HEIGHT: Leave the bar so that it is pulling UP a meniscus of water along its length.

IN SUBSEQUENT EXPERIMENTS YOU'LL HAVE TO REPEAT THE PREVIOUS STEP ANY TIME YOU CHANGE THE WATER **LEVEL**

Step 5) Set the phase switch so that the bar is lifted up and down parallel to the water (rather than rocking back and forth). This SHOULD be the switch's up position – but it is reversed on at least one of our units (you'll be able to check this in the next step).

Step 6) Turn on the wave generator electronics. Use the wave frequency and amplitude knobs to learn how to make waves that give simple clear images on the wave tank screen (try this with and without using the strobe). As you turn up the amplitude, you'll find that the wave image initially improves. But if the amplitude gets TOO high, the image will deteriorate (becoming more complicated and irregular as secondary “harmonic” waves are produced). Further, you’ll find that at low frequencies (below ~ 6 Hz) you’ll need higher amplitudes than will be optimum at higher frequencies.

IN SUBSEQUENT EXPERIMENTS YOU’LL HAVE TO REPEAT THIS STEP ANY TIME YOU CHANGE THE WAVE **FREQUENCY**

When you think you’ve mastered basic wave generation, have the TA or instructor certify this by signing here:

Proficiency demonstrated (TA / Instructor’s initials): ________________

=== RECOMMENDED FOR WATER WAVE LAB DAY 1 ===

Experiment #1) Diffraction (Class's lecture 2 / Manual page 19)

Follow the general instructions for the experiment as called out beginning on page 19 of the Pasco manual.

Place the barriers (the straight plastic pieces with metal rod handles) parallel to the "plane dipper" bar. These barriers should be about half a tank width away from the dipper bar. This will allow you to see the waves before and after they pass through the barriers.

Demonstrate the onset of diffraction when the wavelength of the wave exceeds the size of the gap.

Do this in TWO different ways:

a) With fixed barriers, changing the wavelength of the wave

b) With fixed wavelength, varying the gap by moving the barriers

Diffraction means that it is impossible to focus or constrain a wave into a beam narrower than its wavelength (via lenses or shadow masks). In fact, as you should have seen, if you try this the beam instead expands rapidly into a circular wave.

This is the reason microfabrication technologies, which are based on light micro photography, cannot produce nanoscale objects. This failing fuels nanoscience's search for alternative "self-assembly" techniques.

When you are ready to demonstrate the onset of diffraction by both methods, have the TA certify by signing here:

Demonstrated (TA / Instructor's initials): ________________

Experiment #2) Refraction of lenses and prisms (Class's lecture 3 / manual pages 16-17)

Remove experiment #1's barriers from the tank. Identify the yellow "Convex Refractor" which represents a lens (manual, page 4, item #17). Wipe a very small amount of "surfactant," a.k.a. liquid soap (manual, page 4, item #19) across the entire top surface of this lens.

Place this lens in the center of the tank, parallel to the dipper bar, with its curved edge closest to that bar.

a) Add or drain water to/from the tank until water **just barely flows over the entire top surface of the lens**. This gives the strongest change in water depth from tank to lens (as a ratio).

- Drive waves across the lens at low frequencies
- Drive waves across the lens at high frequencies

What was the effect, if any, of changing the frequency of the waves?

Now for the BIG QUESTION: WHY might results have changed between a and b?

And from that answer, what do you think would happen if you double the depth of the water?

(Hint: Waves try to move water molecules in a circular motion (little circles for small wavelength waves, big circles for large wavelength waves). If the water moving through the bottom of this circle strikes the bottom of the pond/ocean/tank, its motion is going to be impeded).

c) Now try reproducing Newton's splitting of sunlight into a rainbow by using the starting configuration of experiment 8 (Whispering Walls) to send a beam of plane waves across the triangular portion of the yellow prism (different frequency waves => different color light)

The wavelength/frequency dependent focusing of a lens and prisms is called "chromatic aberration." It can be a huge problem in designing the highest quality photographic lenses. Photographic images are recorded or detected on a single plane (the plane of photographic emulsion or of the CCD imager). But chromatic aberration means that only one color at a time can be perfectly focused by a lens on such a plane.

Demonstrated and answer suggested (TA / Instructor's initials): ____________

Experiment #3) Scattering (Class's lecture 2 / not in manual)

Remove the lens from experiment #2.

In its position, instead stand up on their ends the three small white tubes (sections of ½" plastic pipe) in a widely spaced row.

You'll see waves bouncing off the cylinders. But the important question is how MUCH of the incoming wave's energy is being redirected (scattered). To estimate this, look behind the cylinders. Are there wave shadows *behind* the cylinders (i.e. regions of almost still wave-free water)? These cylinders are hard and thus absorb very little wave energy. So if wave energy is missing behind the cylinders (i.e. there *are* shadows) that energy must be going elsewhere, which is to say it IS being scattered.

Set up incoming waves of varied wavelength.

At a wavelength that does not leave shadows with the small tubes, try instead putting in one of the big rings (the ones split in two halves). Does this larger tube leave a shadow?

Can you now make a general statement predicting the relationship between the size of an object and the size of waves it will scatter?

This experiment explains why manufacturers have chosen to put nanoparticles into sunblock.

It also explains why the sky is blue.

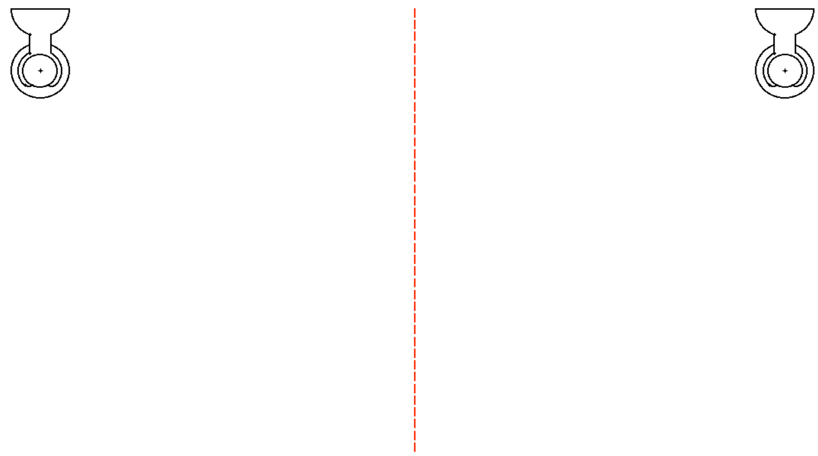
Can you figure out why?

Demonstrated and answers suggested (TA / Instructor's initials): _____________

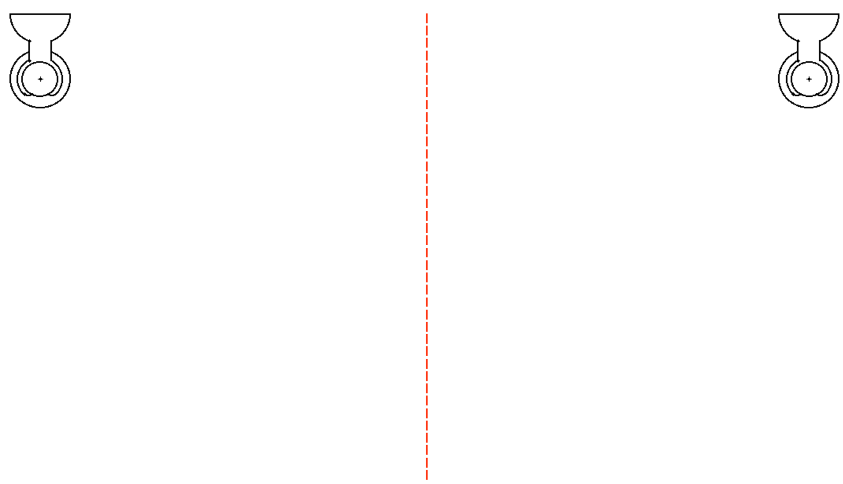
Experiment #4) Interference (Class's lecture 2 / not in manual)

Constructive and destructive interference occur in virtually all of these experiments, but they can be hard to identify. This experiment clearly demonstrates one vs. the other. Remove all objects from the tank. Remove the long "Plane Dipper" wave generator bar and replace it with TWO of the "Standard Dippers" (manual page 4, item 7). Using the "Phase" switch, you can make these two dippers strike the water together (in phase) or in alternation (out of phase).

a) **Out of phase** circular waves should SUBTRACT on the centerline creating a shadowy dead zone. But the waves should also cancel at other points. Add dashed lines below to show the positions of the dead zones (destructive interference bands) that you observe:



b) In phase circular waves should ADD on the centerline producing a bright band of waves. But they should subtract elsewhere producing new dead zones. Add dashed lines below to show the positions of the dead zones (destructive interference bands) that you observe:



This experiment explains why you need to wire stereo speakers properly, or why adding speakers to a theatre or concert hall can create big problems. Can you see why?

Demonstrated and answer suggested (TA / Instructor's initials): ______________

=== RECOMMENDED FOR WATER WAVE LAB DAY 2 ===

Experiment #5) Standing Waves (Class's lecture 3 / not in manual)

Remove one of the two "Standard Dippers" (manual page 4, item 7) used in experiment 4. Move the wave generator so that the remaining single standard dipper is as close to the center of the tank as possible (without having its ring stand touch the tank).

Place the larger white ring around that "dipper" (the rings are cut in half so that you can place them without having to move the dipper). Get the dipper as close to the center of the ring as you can

a) With steady light (no strobe) start at a very low frequency (e.g. 4 Hz) and then gradually increase the frequency (reducing the amplitude to get the sharpest wave at each frequency).

At certain frequencies you will observe sharp strong "standing waves." Write down their frequencies:

____

In lecture it was suggested that the above "standing waves" occur only when the waves had sizes that "fit" into their enclosure. Or specifically, when in a round trip across the enclosure the wave progressed through an integer number of wavelengths.

*If this argument is true, you should be able to predict the standing wave frequencies for another smaller ring: If the ring is 1/2 as big, it should require waves 1/2 as big (i.e. of twice the frequency). See if that works (note that this argument, and this experiment, is the foundation for the **whole** field of "quantum mechanics!"):*

b) Go back and set up one of your lower frequency (longer wavelength) standing waves and note its pattern (i.e. how many bright rings is displays). Measure the inside diameter of this ring. Measure the inside diameter of another smaller ring. From the ratio of their diameters calculate the frequency that will produce the SAME standing wave pattern in second, smaller, ring. Test to see if your calculated frequency does indeed produce the same pattern.

Ring #1: Diameter: _____________ Observed SW frequency: _________

Ring #2: Diameter: _____________ Calculated SW frequency: ________

Observed SW frequency: _________

Calculated and demonstrated (TA / Instructor's initials): ________________

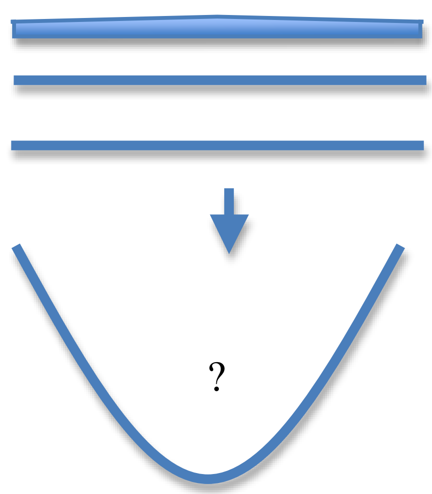
THIS experiment demonstrates the "QUANTUM SIZE EFFECT" which causes nano-objects to change color as they change size.

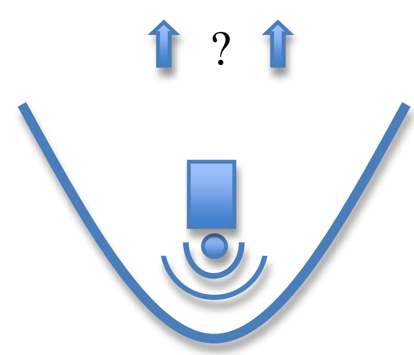
Experiment #6) The Focusing of a Parabolic Mirror

A key design principle for optical devices is that wave phenomena are "reversible." That is, if a wave in one shape moves to form a wave of another shape, you can almost certainly START with the second wave shape and get it to move back into the other shape. This is very useful for testing ideas as, sometimes, the reverse of an experiment can be much easier to set up and validate.

Parabolas have very useful applications that demonstrate this "**principle of reversibility**." If you start with flat (plane) waves, parabolas focus them into a single point. This is the basis for reflecting telescopes, satellite TV dishes, and spy microphones. Working in reverse they are what flashlights use to take the light from a small light bulb/LED and transform it into a beam. A great advantage of such mirrors is that, because they are based on reflection, it makes no difference what the color/wavelength of the wave is (i.e. they suffer from none of the "chromatic aberration" we saw refraction-based lenses). *Bend the flexible drafting ruler we have added to the kit into the shape of a parabola (see drawing last page of this manual). Then:*

a) **Using the straight dipper bar**, send a plane wave into a parabola and see where it focuses (below left). Does this point change with the frequency of the wave? Does this point change if you flatten the parabola out a bit?



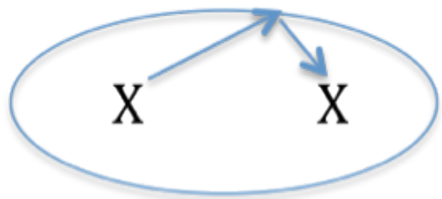


b) **Using a single point dipper**, start a wave at the focus of the parabola (above right). The part of the circular waves moving toward the parabola will reflect - these are the ones we want to watch. But the other half of the circles would proceed forward out of the parabola. We want to absorb these by placing the foam rubber clad wedge right in front of the dipper (mimicking the "beaches" at the edges of the tank). In this way it will be easier to see what the reflected waves alone are doing. By moving the parabola a bit, can you make the reflected circular waves emerge from the parabola as a flat plane wave?

Demonstrated (TA / Instructor's initials): ______________

Experiment #7) The Two Focal Points of an Ellipse

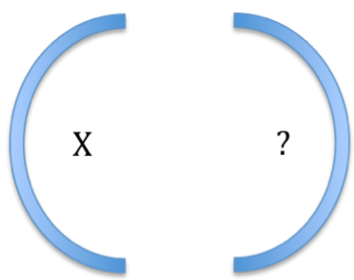
You have probably been told that "waves moving outward from one focal point of an ellipse will refocus at the other focal point."



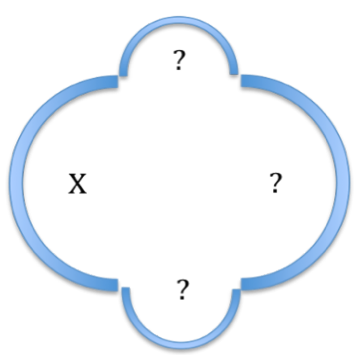
This is used in "pumped" lasers which employ long ellipsoidal mirrors. An intense flash lamp is laid along one focal line and the material to be lased along the other focal line (e.g., a tube of lasable neon or argon gas, or a ruby crystal as in the world's first laser).

It has also been suggested that the U.S. President's Oval Office was designed in the shape of an ellipse to allow him to better hear what others were saying at the other end of the office (hmm . . .with or without their knowledge?).

To test this claimed property of ellipses, you can approximate an ellipse by facing two of the large half circle shapes towards one another. Or, using binder clamps, you can loop two flexible rulers together into a good approximation of an ellipse (using the template sketch provided on the last page of this manual):



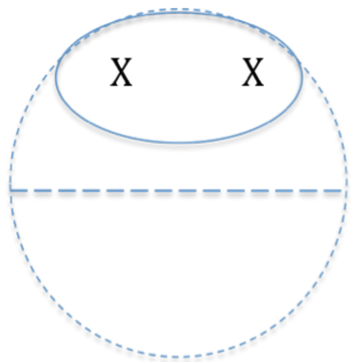
And what happens with THIS shape?



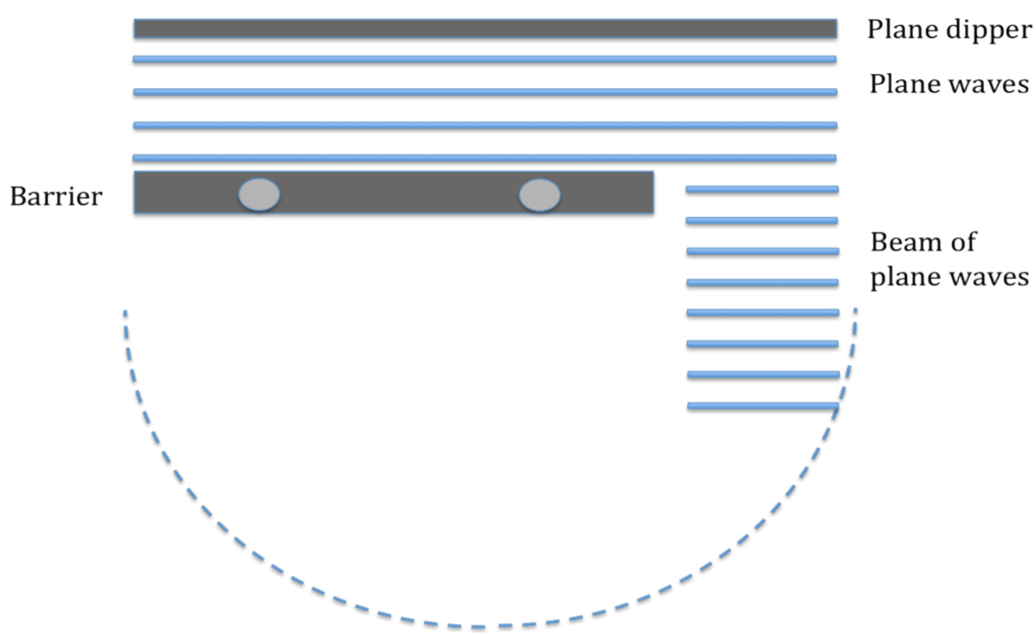
Demonstrated (TA / Instructor's initials): ______________

Experiment #8) Whispering Walls

You may have experienced "whispering walls" that allow two widely separated individuals to "miraculously" whisper to one another. One explanation is that they work because a segment of a curved wall approximates an ellipse. And thus if you stand in the right positions you can get the same focal point to focal point transfer of wave energy seen in the above experiments:



But when Lord Rayleigh observed the whispering wall in the dome of London's Saint Paul's Cathedral he claimed that, in addition to the above effect, there were also sound waves marching (like ranks of soldiers) around the inside wall of the dome (allowing whisperers and listeners to communicate between *any* two points near the dome's wall). His prediction was based on wave interference effects (like those of experiment 4 but complicated by the addition of curved mirrors). You can test his prediction by assembling the plane dipper and long barrier into the configuration below to produce a beam of plane waves. Then, at the position of the dashed curve, add the largest half circle to emulate the dome's inner wall:



Demonstrated (TA / Instructor's initials): ______________

Experiment #9) The Doppler Effect (Pasco Manual, page 29)

The Doppler Effect shifts up frequencies in front of a moving sound/wave source and down behind it. And when the source moves fast enough a supersonic shock wave is formed"

Per the Pasco manual, try to observe these effects by ROTATING the wave generator with one dipper on the collar we've installed on the large vertical rod.

Could you observe a "supersonic shock wave?"

Demonstrated (TA / Instructor's initials): ______________

Additional Experiments

From here on you get to make your own choices on additional experiments, either ones called out in the Pasco manual, or ones you think up for yourself.

We are not specifying the exact number of additional experiments you need to complete. Instead our strong preference is that you take your time, doing the experiments you choose (or invent) as well as you can, fully testing all of the variables and behaviors. If it then turns out that the expectation of five additional experiments is too many – no problem!

Take this as an opportunity to check out some of the things you've been told about waves . . . but are not sure you really believed.

Experiment #10) Your choice of other experiment called out in the manual

Your choice (title / page number in manual):________________________

TA / Instructor's initials: ________________

Experiment #11) Your choice of another experiment called out in the manual

Your choice (title / page number in manual):________________________

TA / Instructor's initials: ________________

Experiment #12) Your choice of other experiment called out in the manual

Your choice (title / page number in manual):________________________

TA / Instructor's initials: ________________

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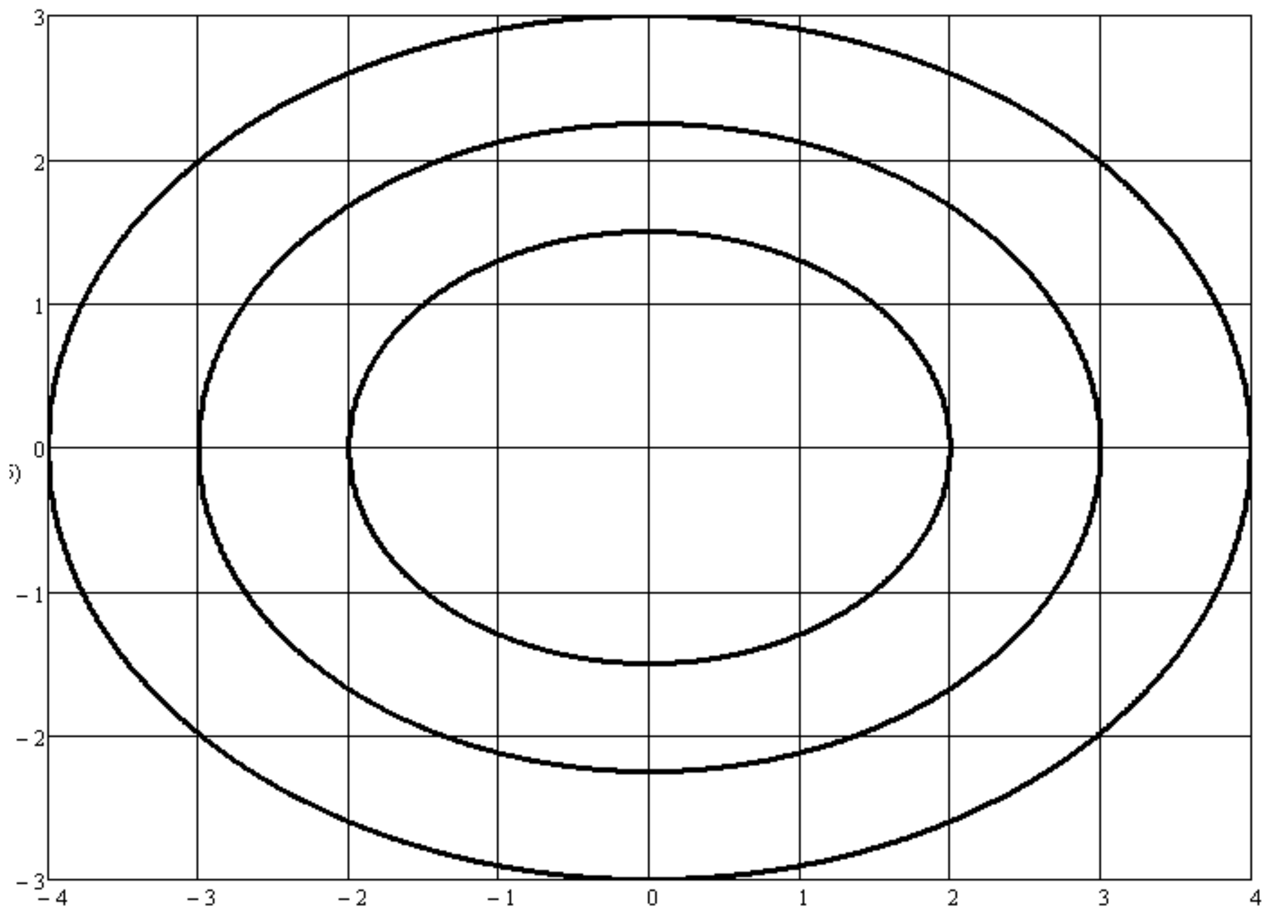

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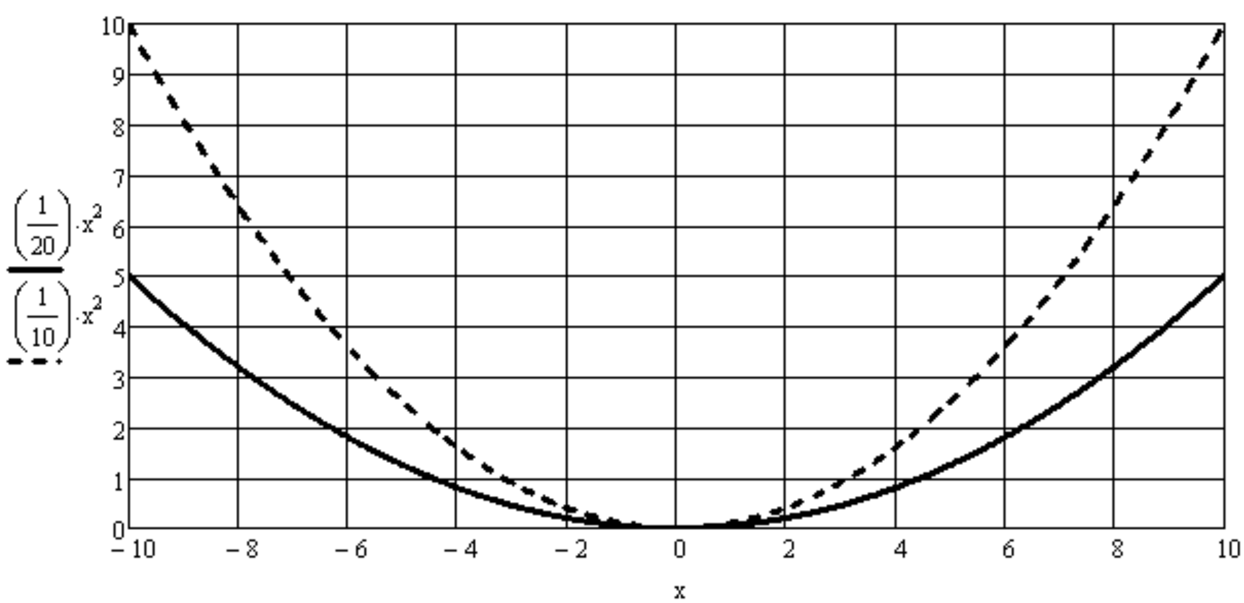

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