Activity: Speaker Project

## GRADE LEVELS: 9-10

## SUMMARY:

Audio speakers are an everyday item in today's world found in televisions, computers, stereos, etc. This project is designed to teach a student about how sound is generated using electrical currents and magnetic fields to produce pressure differentials perceived by humans as sound. Students construct a speaker from raw materials such as magnets and wire while learning vital concepts that describe the theory behind sound generation. A speaker is a very tangible object that most students are familiar with and have interest in developing their own version. The finished product is a speaker through which a student can listen to their favorite song or whatever they please.

LEVEL OF DIFFICULTY [1 = Least Difficult: 5 = Most Difficult]

5, most difficult

TIME REQUIRED

12-15 50 min. class periods

COST

$240 per class of 12-15 working in groups of 2-3 students (magnets are a major cost, having these items donated can drastically reduce price)

## STANDARDS:

2.4 Identify and explain the engineering properties of materials used in structures, e.g., elasticity, plasticity, thermal conductivity, density.

5.1 Describe the different instruments that can be used to measure voltage, e.g., voltmeter, multimeter.

5.2 Identify and explain the components of a circuit including a source, conductor, load and controllers (controllers are switches, relays, diodes, transistors, integrated circuits.)

5.3 Explain the relationship between resistance, voltage, and current (Ohm's Law).

5.4 Determine the voltages and currents in a series circuit and a parallel circuit.

## WHAT WILL THE STUDENTS LEARN?

Electromagnetic Fields

Construction techniques

Pressure and vibrations

Electricity (current, voltage, resistance)

Energy transformation

Design

## BACKGROUND INFORMATION:

This project should coincide with or follow discussions / lectures on electricity, waves, and magnetism. To complete this project, those topics must be covered in reasonable detail since designing and building a speaker is based on those subject areas.

A speaker is an electromechanical transducer. A transducer is anything that changes energy from one form to another. So a speaker must change electric energy (voltage and current) into mechanical energy (moving mass) in this case, vibrating air. The change of energy is done by the interaction of a current with a permanent magnetic field, created using stationary magnets.

The force on a current-carrying wire is equal to the strength of the magnetic field times the current times the length of the wire:

$$F = Bli$$

(Assuming everything to be at right angles)

Before the mechanism of the transducer is explained, a few key terms must first be outlined.

Cone - The cone is the piece of the speaker that actually has to do the work and push the air. It will be attached to the coil and pushed by the coil.
Coil - The coil must carry the current to interact with the magnetic field, and it must be attached to the cone to push the cone up and down. The coil must be the correct electric resistance. The coil needs to be put very close to the magnet poles so that the maximum force can be applied.
Magnetic Field Apparatus - The motion of the cone depends upon the magnetic force that can be placed upon it, so it is important to create a strong and concentrated magnetic field that is pointing in the right direction.
Suspension - The suspension connects the moving cone to the non-moving frame. (Please see figure 1 for a diagram of speaker components)

A speaker receives an input current from the source that is fed through the coil. The shape and resistance of the coil produce an electric field that interacts with a magnetic field already in place. The interaction between the two fields forces the coil to move vertically which pushes the cone. The cone, mounted to the speaker box with the suspension system, moves up and down, vibrating the air to create pressure differentials that are interpreted as sounds by the human ear.

## MATERIALS:

Circular Magnets
36-gauge voice coil wire (5-7 meters per speaker)
Styrofoam cups and plates
Plastic cups, plates, and straws
Paper cups and plates
Index cards

Various adhesives (glue guns, super glue, masking tape, duct tape, Loctite 411, etc.)

Latex rubber sheeting

Flat metal stock, ½ "(iron or steel)

5/8 "Iron or Steel rod (6 cm. per speaker)

Binding posts for speaker leads

Speaker Wire, 16-gauge

Foam Board

Scissors

Utility knives

Rulers

## PREPARATION:

It would be beneficial to produce a prototype of certain parts of the speaker for the students to use as a model. Specifically, the Magnetic Field Apparatus should be constructed so that students know what the final product should look like. This is a crucial component in the speaker and accuracy has a significant impact on the quality of sound produced by the speaker. Other speaker components can be explained as students get to a point where they're ready to build them. Cone design and speaker box design should be left up to the students; this is where design freedom comes into the picture. Suggestions for box size should be made and materials should be limited so that the projects do not become monstrosities, but good judgment has to be used here based on material costs and supplies available.

## DIRECTIONS:

Please see attached worksheets: General Assembly Guidelines, Magnetic Field Apparatus.

## INVESTIGATING QUESTIONS:

Cone Design

1. What do we need to think about in designing a cone?
2. Should it be big or small? Heavy or light? Stiff or floppy?
3. Does shape matter?

Coil Design

1. Why does coil resistance make a difference?

Magnetic Field Apparatus

1. What is the best way to orient the magnetic field? How can we do this?

Suspension

1. Should if be stiff or compliant? How elastic should it be?
2. Heavy or light?
3. Wide or narrow?

Box Design

1. Why must the box be as close to airtight as possible?
2. What will loose construction of the box produce? Loose construction meaning weak joints and loose connections.

Rubric for Performance Assessment

# Activity Title: Speaker Project

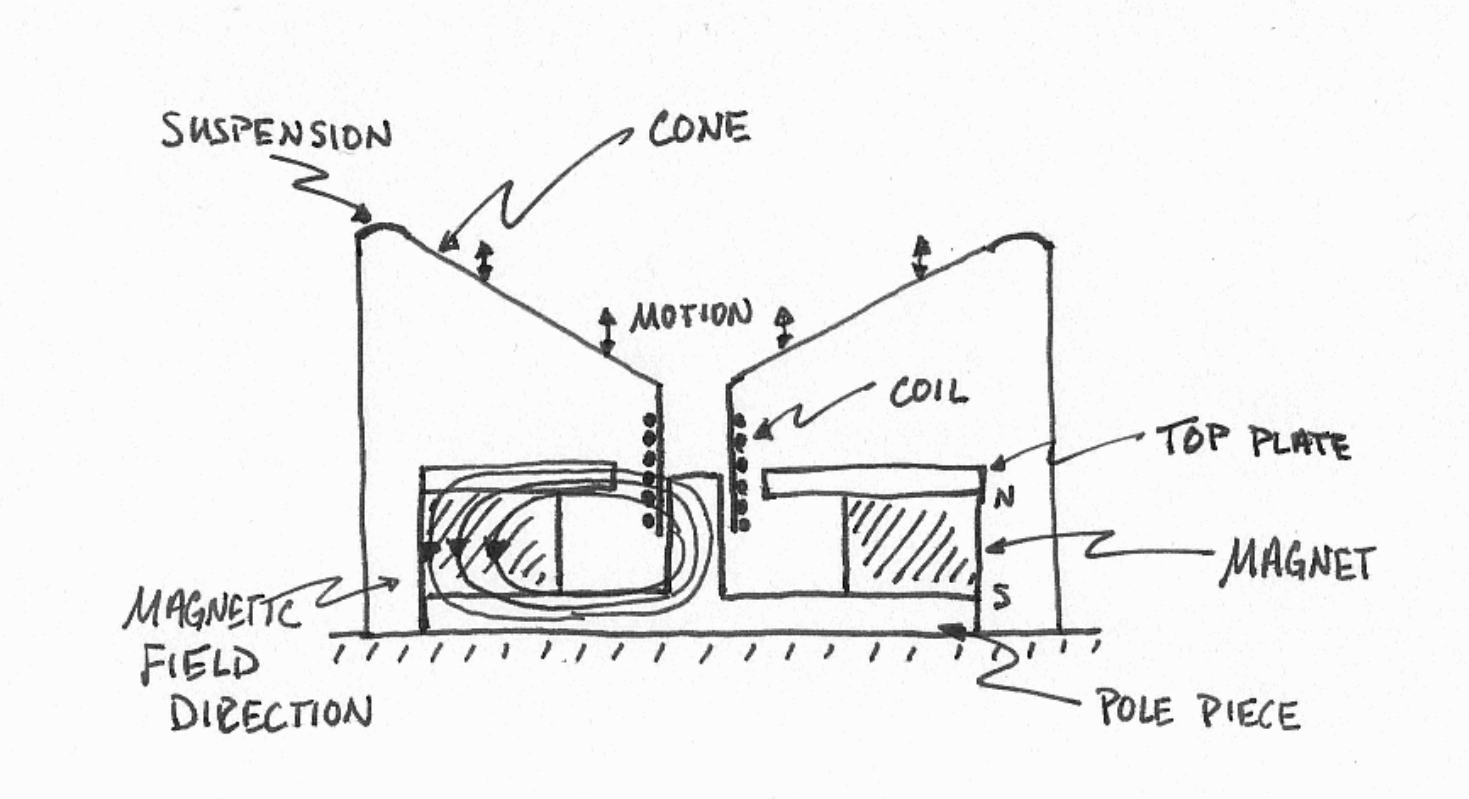
Grade Level: 9-10

| | 1 | 2 | 3 | | |
|---|---|---|---|---|---|
| *Criteria* | Developing | Proficient | Advanced | Weight (X factor) | Subtotal |
| Group Work | Little to no contribution to group work. | Moderate contribution to group work. | Contributes as expected to group work. | | |
| Construction | Initial Drawings, no finished product | Project completed at sub-par level, doesn't necessarily work | Speaker works, well constructed, looks good | | |
| Write-Up | Completed little to no guidelines | Completed Guidelines with minimal effort | Completed all guidelines thoroughly and went beyond what was required | | |
| | | | | ***Total:*** | |

*Teacher Comments:*

Figure 1 – Speaker Diagram

The following diagram is a cross sectional view of a speaker assembly with all components labeled and the direction of the magnetic field identified.



**Speaker Project**
**General Assembly Guidelines**

**1. Assemble Magnetic Field Apparatus**

See attachment.

**2. Construct Cone Assembly**

Winding the coil

The coil will move up and down in the magnetic field around the pole piece driving the Styrofoam cone. For maximum effect, the coil should fit closely around the pole piece without touching it. Therefore it is important that the coil be made carefully and kept **square** and **round**.

a. Use 36-gauge voice coil wire for coil (you can try a different gauge if you would like – see the instructor). Handle with care: this device is very fragile.
b. Desired impedance (DC resistance) between 7 & 8 Ω. Find DC resistance of 1 m of wire to determine overall length of wire needed. (Leads need to be *carefully* sanded).
c. Wind the coil on an index card with a two-index-card tolerance around the pole piece. That is, wrap 2 index cards around the 1/2" rod; these two are just spacers. Be sure that they go an even number of time around (to keep everything circular) – trim if necessary. Then take a third index card and cut and scotch tape it to fit over the two spacers. Wrap your coil on this third index card. *Confusing*
d. Leave 8-10" (12-25 cm) leads at ends of coil wire.
e. Keep outside edge of coil approximately (at least) 1 cm from "cone end" of index card. **Make sure cone end of index card is square.**
f. Make neat coils and keep them perpendicular to the longitudinal axis of the index card – the neater and the more perpendicular the coils, the stronger the magnetic field produced by current flowing through the coil, the more force generated on the coil by the permanent magnet, and the more efficient the speaker.
g. To make things easier, glue coils down every once in a while as you go with Loctite adhesive 411. Apply adhesive, then apply accelerant. **Only use tiny amount! This stuff is very expensive and you only need the tiniest drop!**
h. Wind the coil with slight tension. Too much tension will easily stretch the wire. Stretching the wire increases its resistance (by reducing the cross sectional area). Increasing resistance reduces current, which in turn reduces the interaction with the magnetic field. Stretching wire can also stress the index card unevenly, pushing it out of round.
i. Coil width should be about 0.7 cm. This way some of the coil windings will remain in the magnetic field as the coil is pushed up and down.
j. Trim "free end" of index card. Excess paper may rub on pole piece.
k. Carefully sand the enamel from the last 2 cm or so of the coil leads. This is necessary to ensure electrical contact.

l. When finished, use a multi-meter to check the DC resistance of the coil; be sure it is in the 7 Ω range, **no less than 6 Ω**. This is critical. If the DC resistance of the coil is too low, your speaker will tend to over-draw current from the amplifier.

## Choosing a cone

After considering all of the factors that go into what makes a good cone, discuss it with the instructors and design and construct a cone.

## Attaching coil to cone

In a speaker, the coil is attached to the cone. When electric current flows through the coil, it will be pushed by the magnetic field; the coil in turn pushes on the cone. The cone will then push the air, creating sound.

a. Before attaching the coil to the cone, check the tolerance. It is important that there is tighter tolerance between the coil and the pole piece than between the coil and the arms of the magnetic field apparatus. The reason for this is thus: since the coil is on the outside of the index card, id there is rubbing between the coil and the pole piece, there will be distortion and loss of efficiency; however, if there is rubbing between the coil and the arm, it is possible for the coil to be damaged. It should be impossible for your coil to contact the arms of your magnetic field apparatus.
b. First, find the "center" of your cone. This "center" is the center of push, which may not be the geometric center of your cone (because of lack of close tolerance in the manufacture of the cone). Push on the plate a little and try to feel where the push is the most even. Mark this spot.
c. Apply hot glue to index card and glue card/coil to plate. **Keep it square!** This is critical: if the coil is not square to the cone, then some of the push on the cone will be sideways. The sideways push will be a source of inefficiencies and will create distortions of the sound.

## Finishing Cone

In order to get a "clean" sound (i.e. sounds that is a true representation of the input signal) it is important that the cone be stiff enough that its shape does not physically deform while being driven. If the cone shape deforms during operation, this will create waves not a signal and will lead to distortion of the sound.

a. In theory, creating a cone that is both lightweight and still could be done in a variety of ways using different design materials and geometries.
b. Depending on your cone, you may need to stiffen it to make it into a proper speaker cone. This could potentially be done in a variety of ways. You can brainstorm and evaluate possible solutions if you would like. Remember that whatever you do, keeping the cone mass low is important.

c. Try to avoid any rough edges on your stiffeners, extraneous glue "threads," or anything else that could possibly buzz or rattle; they will introduce noise into your speaker performance.

**3. Assemble Box (Partial Assembly)**

- Box will be made of 3/16" foam board, which is reasonably expensive. Please don't waste the foam core.
- For 9" cone, overall dimensions of box: 10.5" length x 10.5" width x 9" height.
    - Top and bottom pieces: 10.5" x 10.5"
    - 2 side pieces: 9" x 10.5"
    - 3rd side piece: 9" x 10 1/8"
    - 4th side is divided into two pieces: 2" x 10 1/8" and 7" x 10 1/8". The 2" piece will be the top of the 4th side. The 7" piece will be the bottom of the 4th side.
    - Match the size of the box to the cone in a similar manner if you have a smaller cone.
- These pieces will not quite fir on one 20" x 30" sheet of foam core. The top, bottom, and three side pieces can all be cut out of one sheet (with an approx. 9.5" x 9" piece left over).
- 5 teams can cut their fourth side out of one sheet of foam core. Coordinate with the instructor.
- Finish all foam core edges with duct tape; this will allow for the box to be taken apart or modified without delaminating the foam core.
- Cut a hole in the top of the box approximately 1/2" larger than your cone; this is where we will suspend the cone. Do a good job cutting the hole, keeping the edges smooth. Any loose ends or strands will buzz when the speaker plays, creating noise. (Don't finish this edge).
- Put the box together using hot glue.
    - Leave the top off as well as 7" x 101/8" sidepiece.
        - We still need to attach the cone and suspension to the top.
        - Leaving off the 7" sidepiece will allow us to access the inside of the box so we can put in the magnetic field apparatus, etc.
    - Be sure to construct the box with 10.5" outside dimension; that is, the side pieces rest on the bottom piece, the side pieces do not go on the outside of the bottom piece.

**4. Suspend cone to top plate of box**

The suspension attached the cone (which moves) to the stationary parts of the speaker. In a commercial speaker, the suspension attaches the cone to a frame, and the whole assembly is mounted in a box. The suspension is important and highly engineered. Ideally, the suspension must be somewhat compliant (opposite of stiff) in the forward and backward direction to allow the cone to vibrate the air, but needs some elasticity, especially at the limits of range, to be sure to pull the coil back into the magnetic field at the limits of range; however, the suspension must be extremely stiff in the sideways

direction so that the coil does not move sideways and contact and part of the magnetic field apparatus, leading to distortion of the sound or damage to the coil.

- For our speaker, we will not build a separate frame per se. Our cone will be suspended from the top piece of our box.
- We have a couple of materials to use for the suspension: plastic wrap and three different thickness of latex rubber sheeting.
- The basic idea is to cut out a ring of material about 2-2 1/2" wide: inside diameter about 1" less than your cone, outside diameter about 1 1/2" larger than your cone. (A little bigger gives more surface to glue; a little smaller is less mass to move). You may need to trim a little to fit box top.
- We will glue the suspension to both the plate and the box top. The idea is to center the cone in the hole and get an even radial tension (slight tension) into the suspension (the tension if to prevent lateral movement of the coil). The best method for doing this is not certain. Some experimentation may be necessary. I had some success with the following:
    - glue the suspension first to the underside of the plate.
    - apply glue to the underside of the box top.
    - then gently pulling on opposite sides of the suspension, press it down to the box top.
    - continue to attach the suspension to the box top; always attempt to have an even pressure on opposite sides; remember, the overall goal is to get the plate centered in the whole with a alight even radial tension in the suspension.
    - be sure not to have any ruffles or ripples in the suspension; these will lead to buzzes or other undesirable sounds; glue right to the edge of the plate and the box top.
    - finish off by duct-taping suspension ends on box top for extra support.
- The best glue/adhesive for this job is not known, experiment with different alternatives.

**5. Design and build support structure (frame) for Magnetic Field Apparatus**

- Design Requirements:
    - Must support magnetic field apparatus within box.
    - Must hold magnetic field apparatus in proper alignment with coil.
    - Must have place of attachment for coil leads (the will be glued down).
- Design Constraints
    - Materials limited to whatever can be salvaged from previous projects or whatever you can provide yourself.
    - Important consideration: the magnetic filed apparatus must be precisely aligned; it is important that you consider how you are going to build in adjustment capability (i.e. how are you going to be able to shim your frame before you glue it down).

**6. Align pole piece of Magnetic Field Apparatus with coil of Cone Assembly & attach to box**

Proper alignment is critical. The coil needs to be centered on the pole piece with no rubbing and the coil needs to be centered on the arms of the magnetic field apparatus. Rubbing of the coil on the pole piece will lead to horrible losses of power and distortion; and the middle of the coil needs to be lined up with the arms of the magnetic field apparatus to ensure maximum interaction with the magnetic field. Alignment may be done by shimming and adjusting the magnetic field frame, the box top, or some combination of the two. When everything is properly aligned, glue everything in place. Be sure that things don't shift in the process of gluing.

**7. Finish electrical & finish box**

The basic idea of the finish work is to bring the electrical connection to the speaker (coil) to the outside of the box, then seal the box airtight. The general procedure is to solder one end of a length of 16-gauge speaker wire to the coil leads and the other end to the binding posts. Then to glue the whole thing down so it doesn't vibrate and create noise. The exact procedure will depend a bit upon your frame design.

The general procedure:

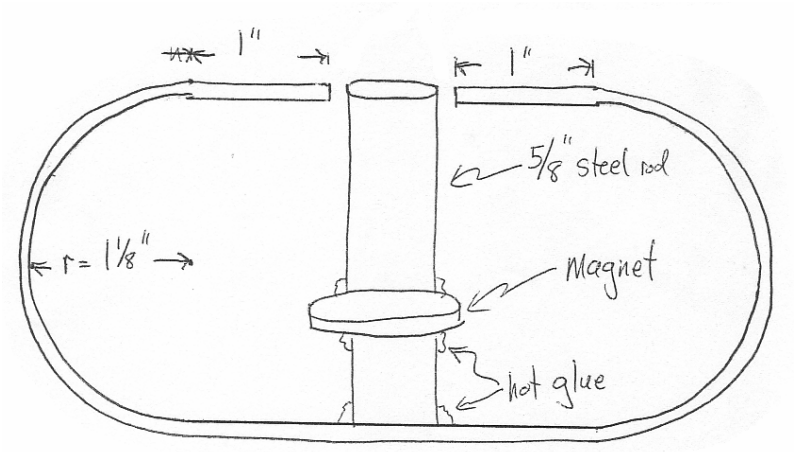
- Get a pair of binding posts (one black, one red). The binding posts will be mounted through the box; they will be the point of attachment on your speaker for the wires coming from the amplifier. Figure out where on your box you are going to put your binding posts; choose a place that is easy to get to and will use the minimum speaker wire (remembering that the wiring needs to be glued down).
- To mount the binding posts, drill two 5/16" holes approximately 3/4" apart. Remove hardware from post and save; push colored mushroom-shaped piece into hole from outside. Put post into mushroom piece from outside. From inside, put colored washer, then metal washer, then one of the nuts. Tighten, but not so much that you crush the foam board. The little metal tab with the hole goes next (the speaker wire will be soldered to it), then the second nut.
- Trim and re-sand the coil leads. Different groups may trim their leads to different lengths. Considerations for length: shorter the better – less wire to rattle; but you need a length that will be convenient to solder to and glue down to your frame. After trimming, recheck coil impedance to be sure leads are properly sanded.
- Take the correct length of 16-gauge wire (double stranded). Strip ends approximately 1 cm. Put each of the two strands of one end of the speaker wire through the small hole of a binding post tab. Solder.
- Twist one coil lead and one strand of the other end of speaker wire together. Solder the coil lead and speaker wire strand together. Be careful: remember the 32-gauge voice coil wire is extremely fragile. Repeat with the second coil lead and second speaker wire strand.
- Attach other end of speaker wires/tabs to the binding posts.
- Carefully hot glue the coil lead/speaker wire assembly to your frame or the box.
- Seal box. Begin with temporary seal (a little duct-tape) to allow for easy access to the inside during testing.

# Speaker Project

## Magnetic Field Apparatus

1. Cut 12” piece of flat steel or iron stock. File edges square.
2. Bend as indicated.
3. Cut 5/8” steel or iron rod:

    1 - 4cm. piece, 1 - 2cm. piece (keep it square!)




4. Assemble bent stock, magnet, and steel rod as shown.
    - Square & center rod in gap; want about a 1/8” gap on each side.
    - use hot glue to hold pieces together & to square pieces as necessary.

**Speaker Project**

**Write-Up Guidelines**

1. Overall purpose and function of the speaker.
   - Describe what the speaker does and how the speaker does it.
   - Be sure to include some background information on sound and waves.
   - Include all requirements and any constraints on the speaker.
   - Be sure to answer the question, "What makes a good speaker?" in some way or another.

2. Application of magnetic field theory to speaker design
   -Explain in as much detail as possible how the magnetic field of the permanent magnet interacts with the coil of the speaker to produce the desired motion of the cone.
   - Include a drawing or drawings showing the magnetic field, the current in the coil, and the resultant force on the coil. Prove that you understand how currents interact with magnetic fields.
   - Explain the function of the magnetic field apparatus. Explain the effect of a longitudinal field on a coil and the effect of a radial field on a coil (with the center of the coil as the axis of the radial field). Remember from our motor how the coil reacts to a uniform field in one direction. How does the magnetic field apparatus produce the most desirable effect for our situation? You may include a drawing.

3. Important design, construction, and troubleshooting considerations.
   - Explain the important aspects of the cone, suspension, frame, box, etc. What do they do? What specific characteristics are needed by each component in order to produce a high quality product?
   - What are the keys, from a design standpoint, to producing a high quality speaker?
   - What are the keys, from a construction standpoint, to producing a high quality speaker?

- We did not get the opportunity to take and analyze quantitative data. If you had the opportunity, describe a "Speaker Testing Regimen" that you would like to have performed. What data would you like to have collected? How would you have analyzed it?

4. Improvements to design and final thoughts
   - What are the weaknesses of the current prototype design and what solutions could you offer to improve the design?
   - Final additional thoughts.

PreK-12 ENGINEERING

Activity Evaluation Form

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**Activity Name:** _____

**Grade Level the Activity was implemented at:**_____

**Was this Activity effective at this grade level** (if so, why, and if not, why not)**?**

What were the Activity's strong points?

What were its weak points?

**Was the suggested Time Required sufficient** (if not, which aspects of the Activity took shorter or longer than expected)**?**

**Was the supposed Cost accurate** (if not, what were some factors that contributed to either lower or higher costs)**?**

**Do you think that the Activity sufficiently represented the listed MA Framework Standards** (if not, do you have suggestions that might improve the Activity's relevance)**?**

**Was the suggested Preparation sufficient in raising the students' initial familiarity with the Activity's topic** (if not, do you have suggestions of steps that might be added here)**?**

**If there were any attached Rubrics or Worksheets, were they effective** (if not, do you have suggestions for their improvement)**?**

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