Title: Research Skills - Lecture 3A

Date: Aug 20, 2010 09:00 AM

URL: http://pirsa.org/10080005

Abstract:

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Transistors



Joel Lamy-Poirier

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Transistors



Joel Lamy-Poirier

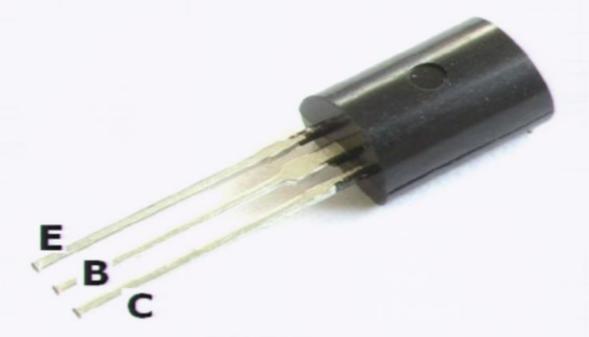
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Outline

- What is a transistor?
- How does it work?

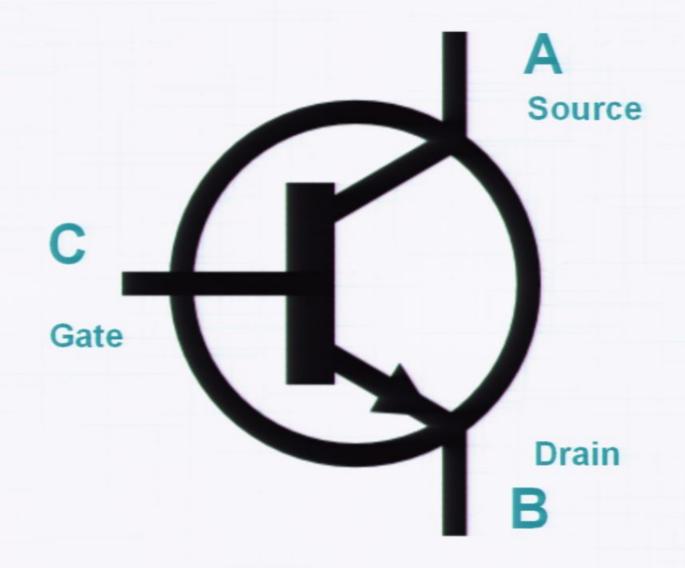
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What do we use them for?



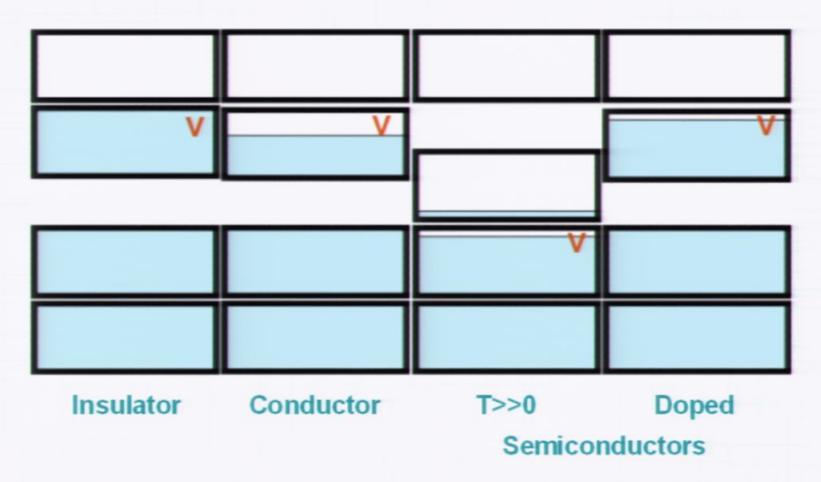
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What is a transistor?



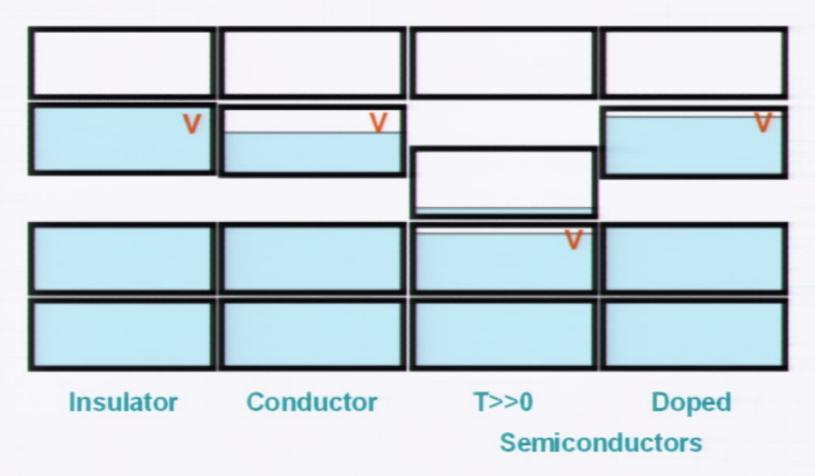
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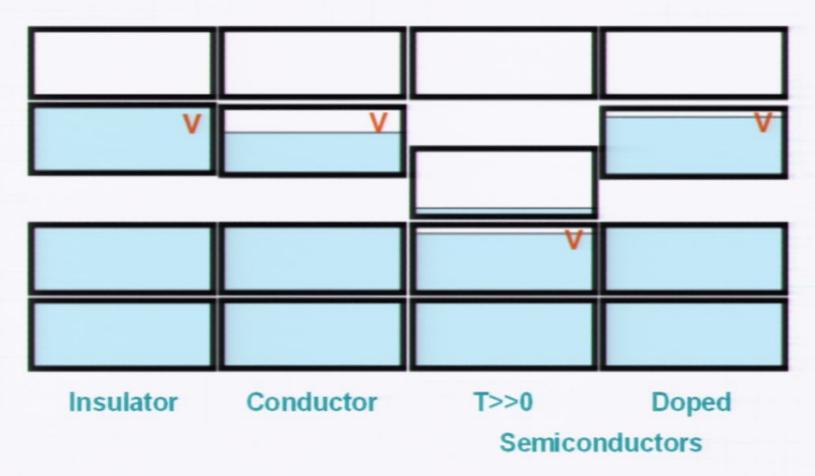
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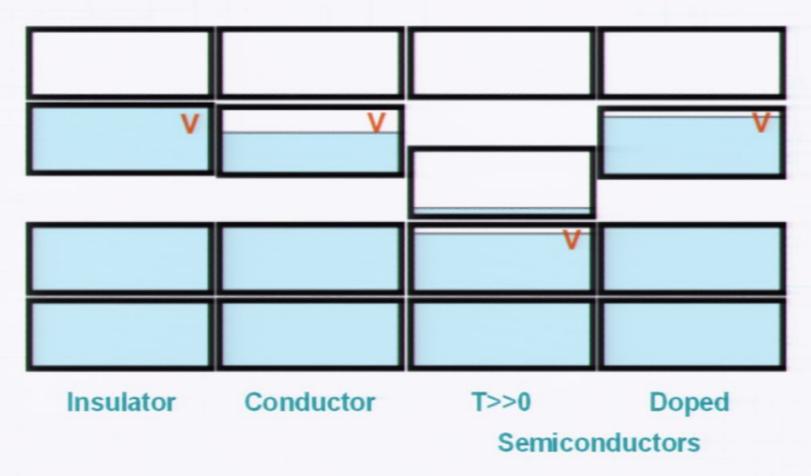
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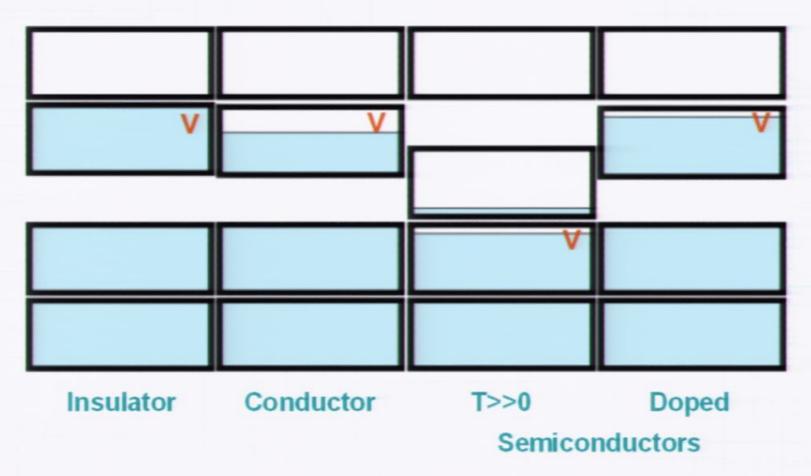
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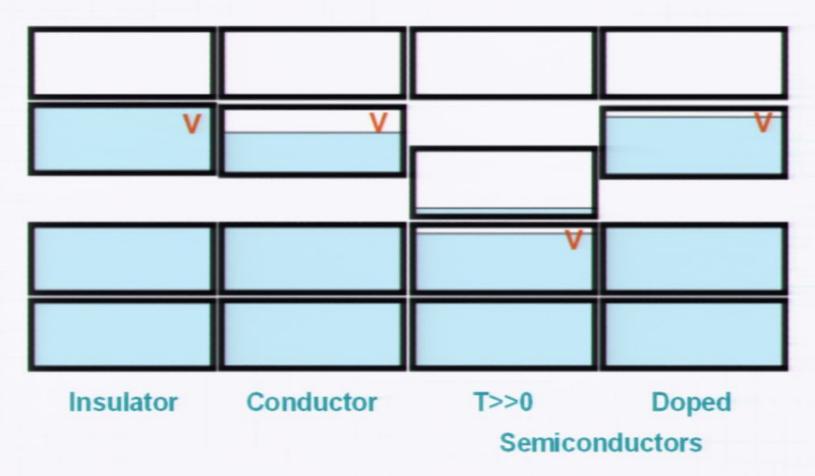
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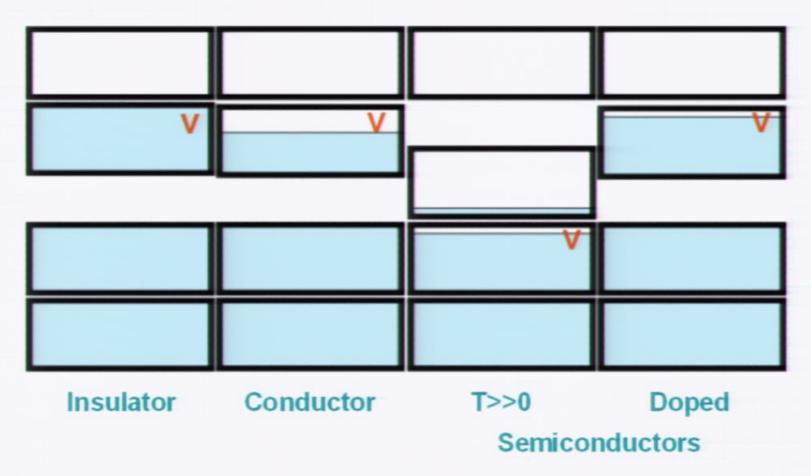
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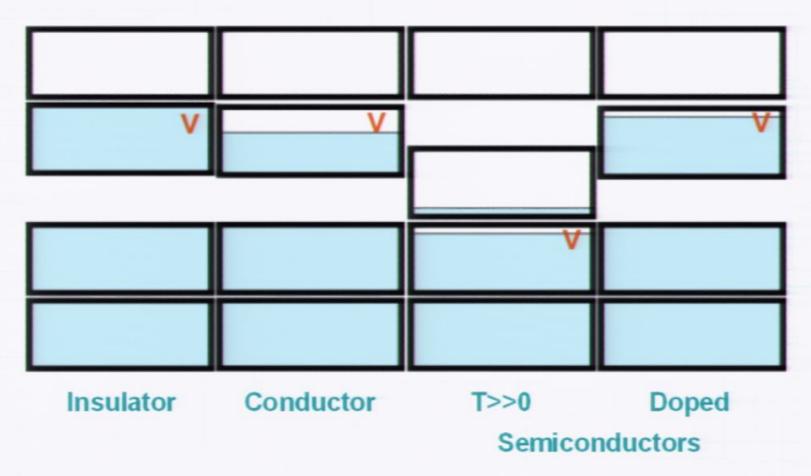
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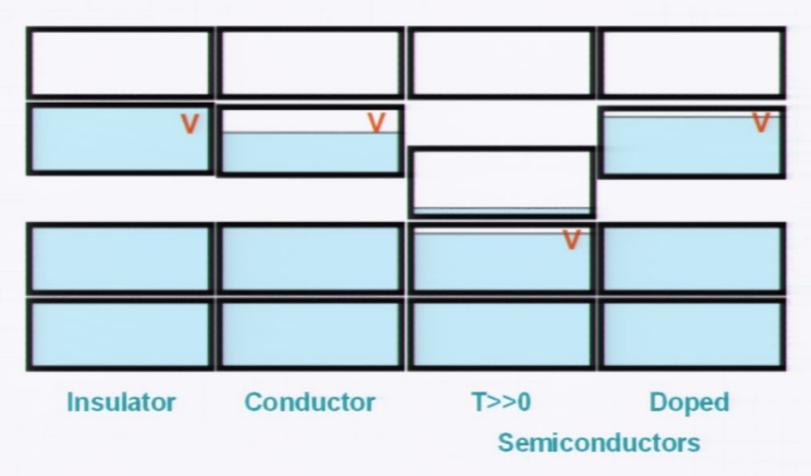
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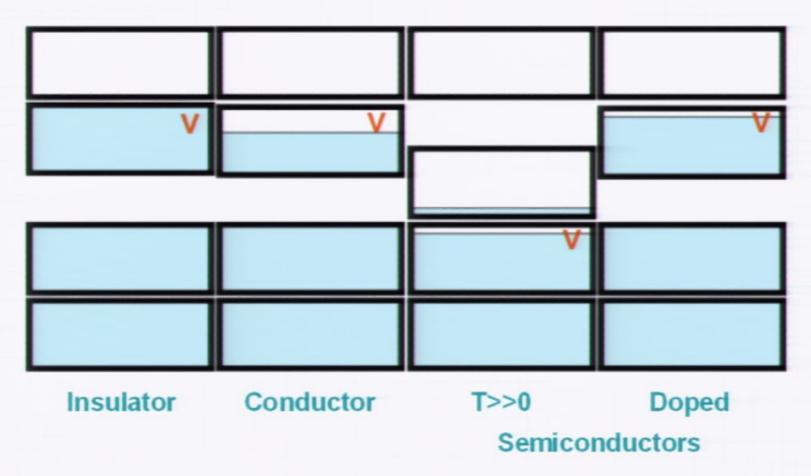
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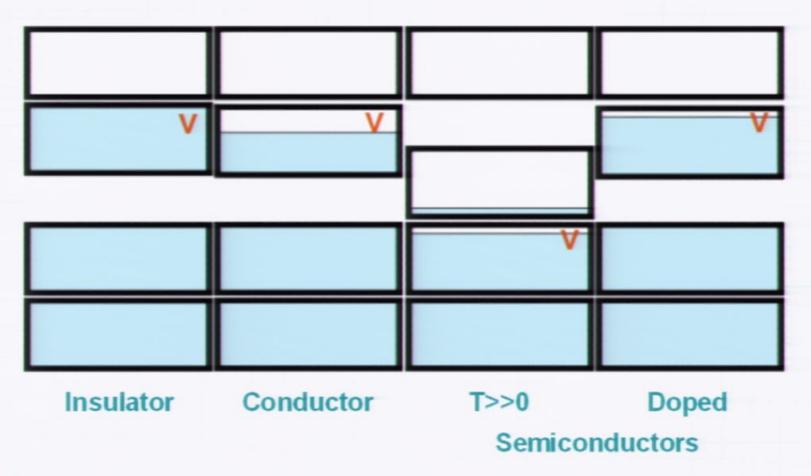
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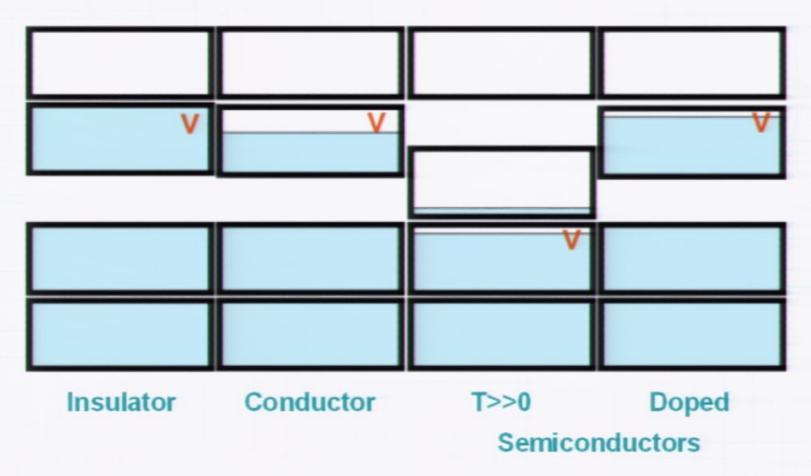
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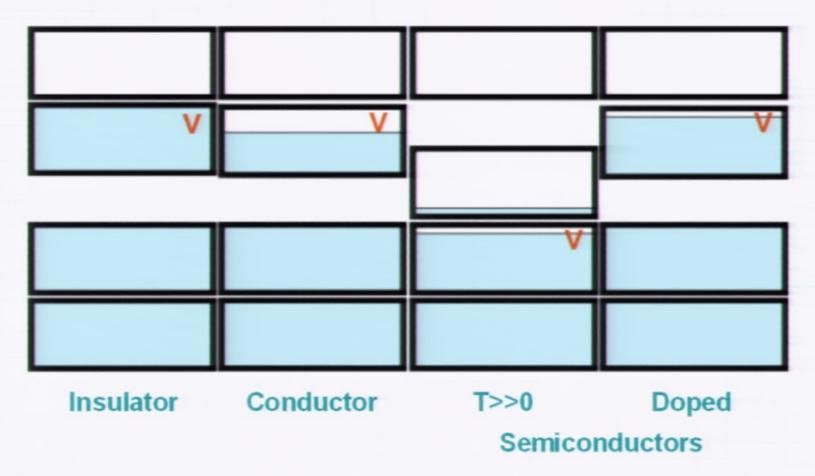
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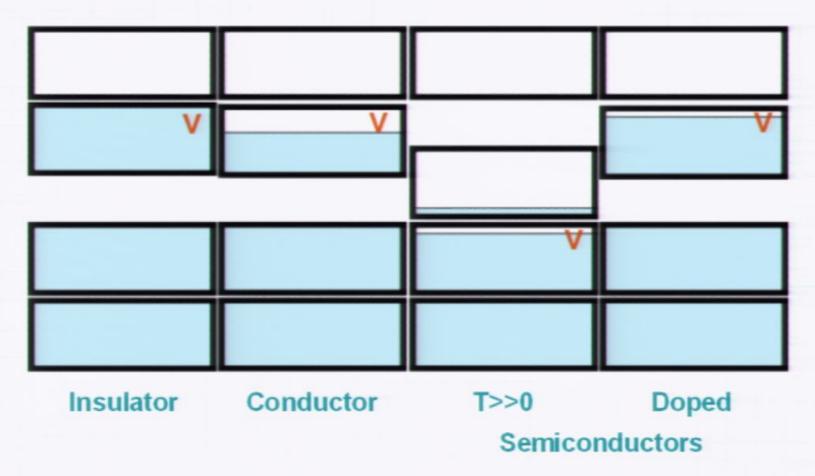
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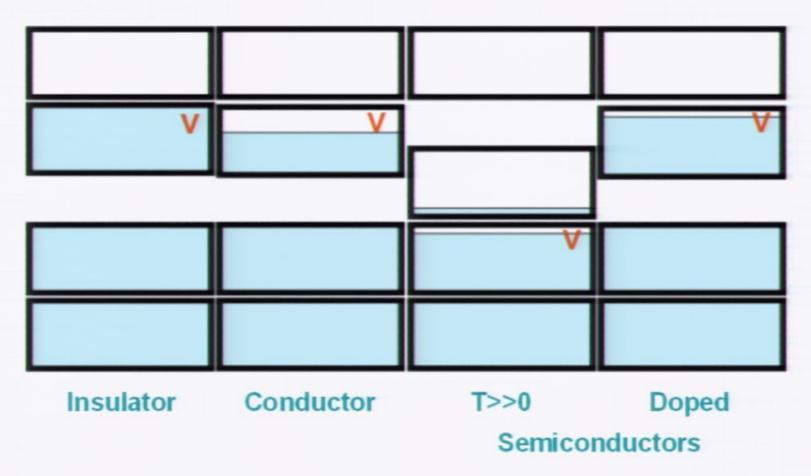
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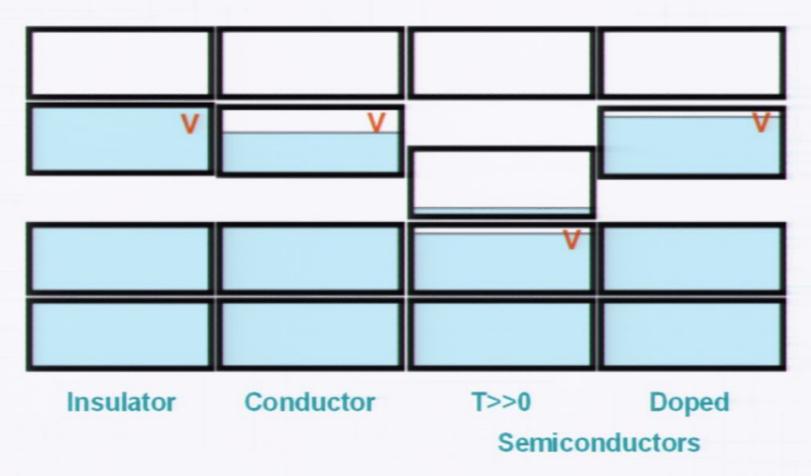
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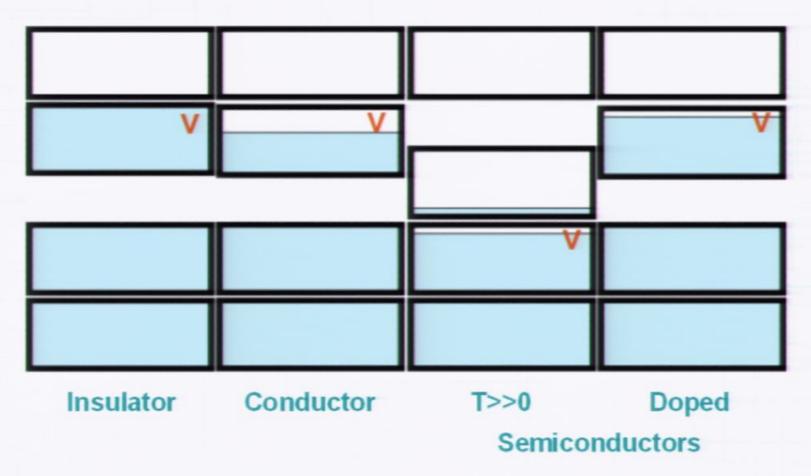
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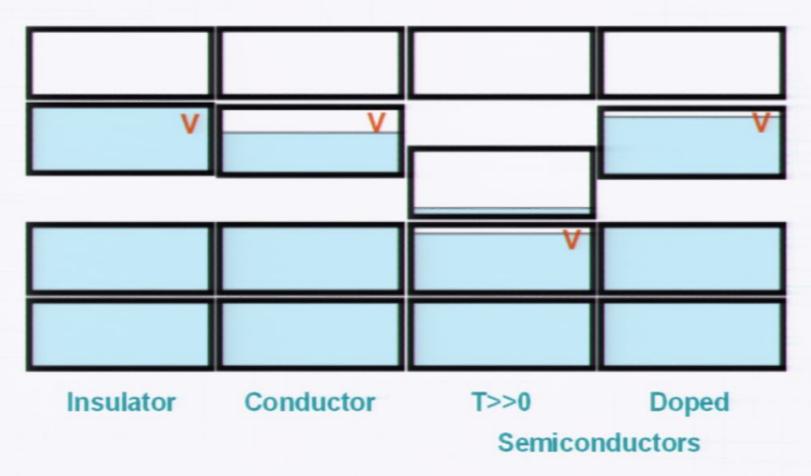
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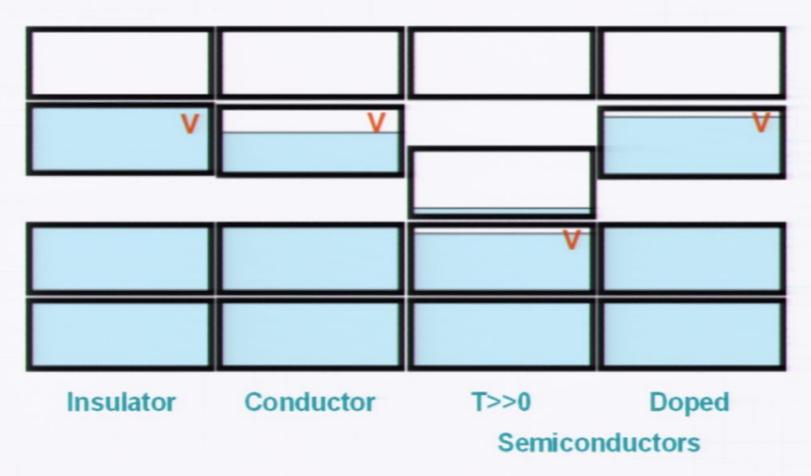
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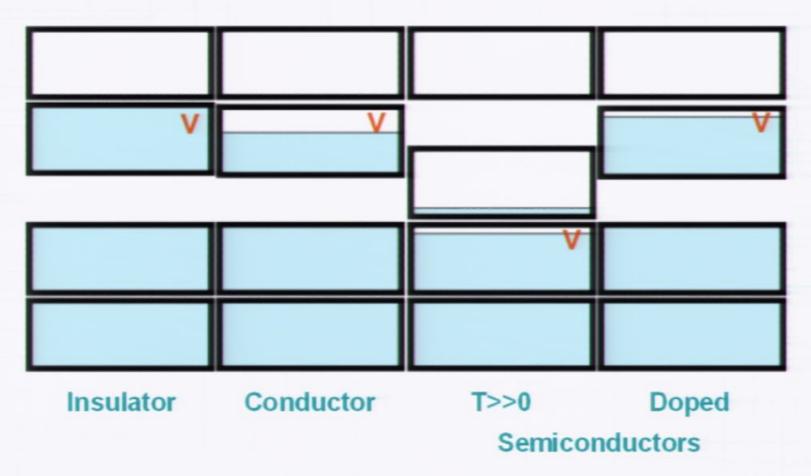
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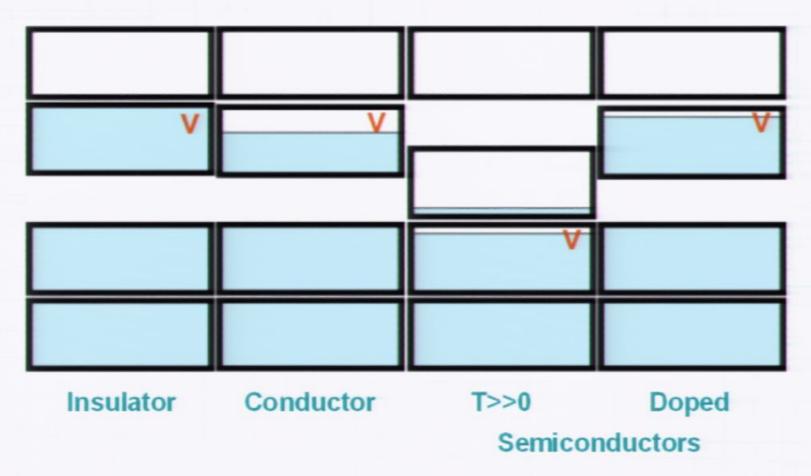
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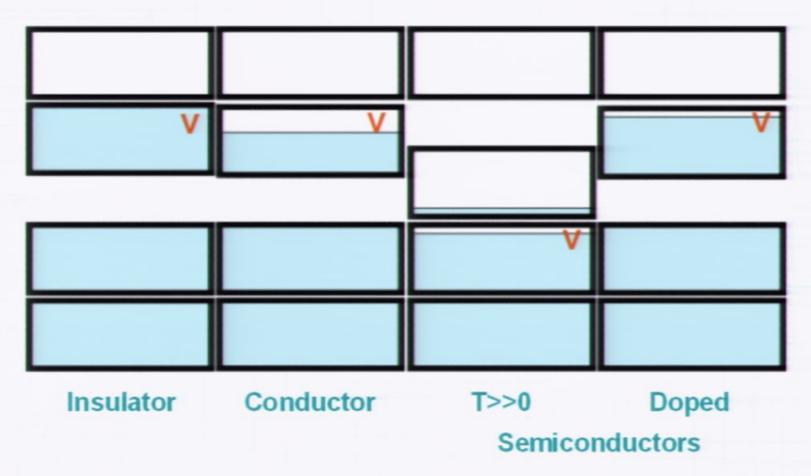
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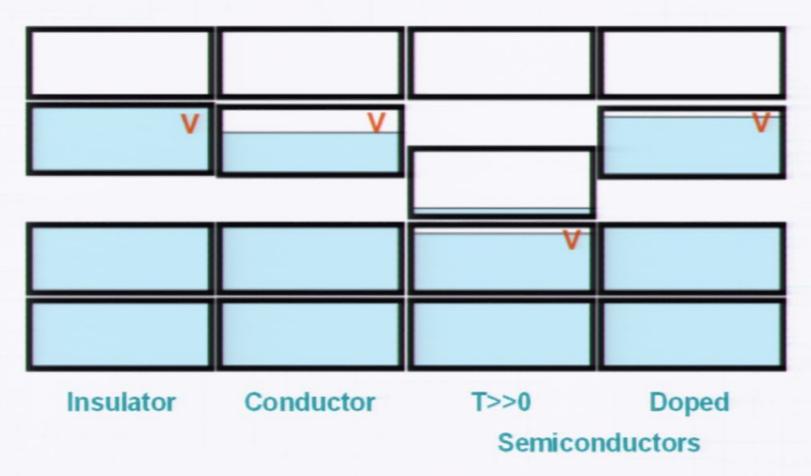
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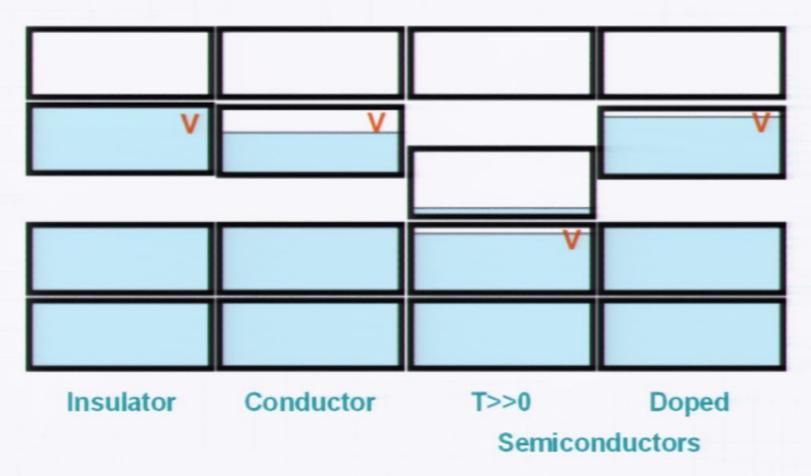
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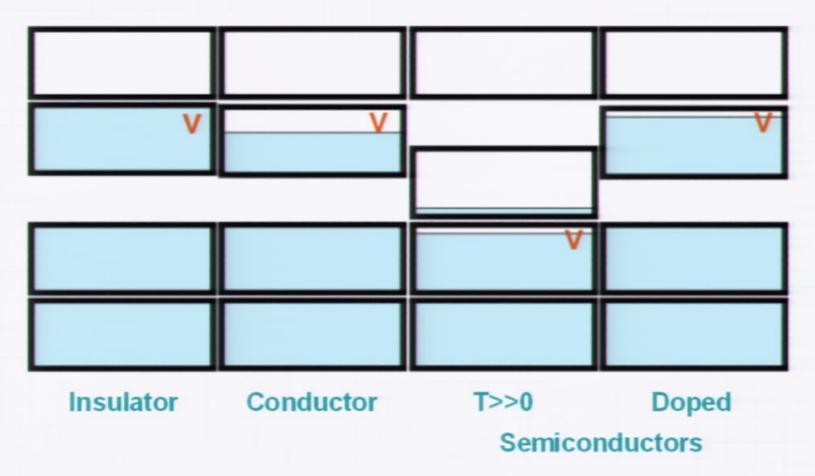
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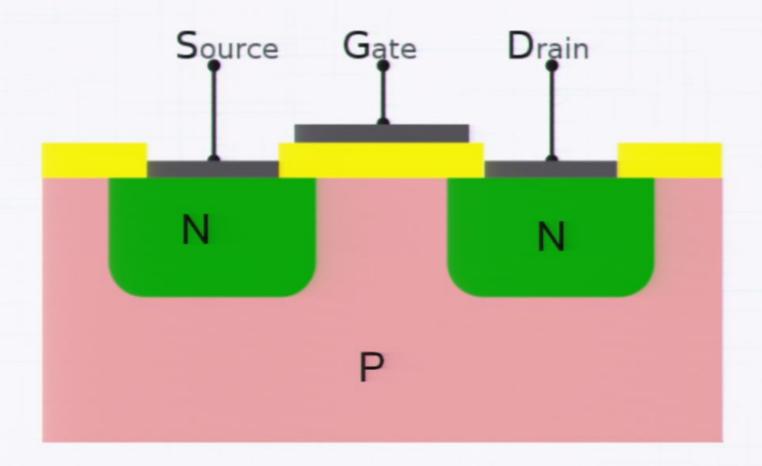
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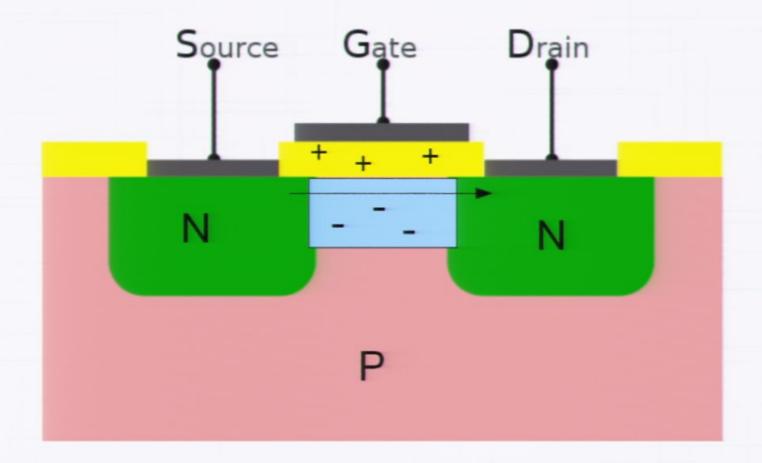
How does it work Field effect transistor (MOSFET)



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How does it work Field effect transistor (MOSFET)



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How to use them

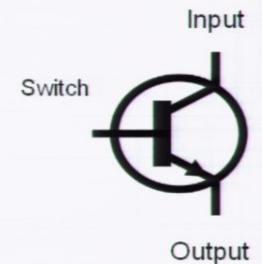
Amplification

On/Off switch

Power source



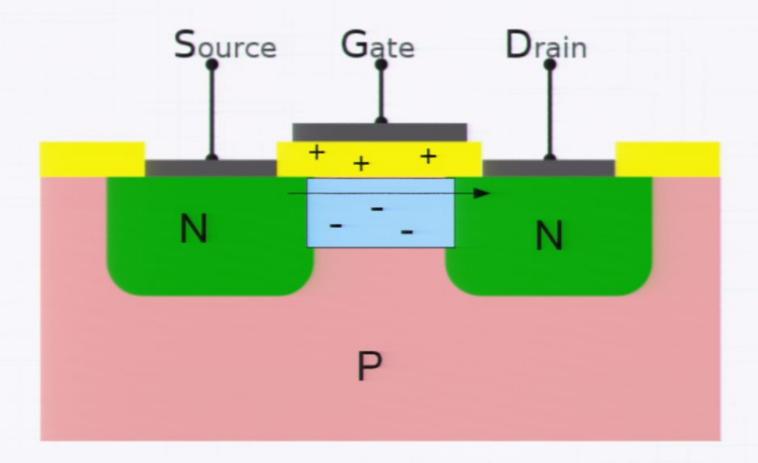
Amplified signal



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How does it work Field effect transistor (MOSFET)



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How to use them

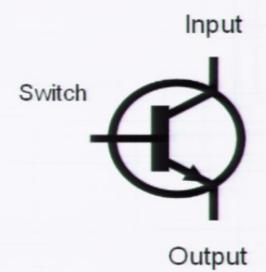
Amplification

On/Off switch

Power source

Small signal

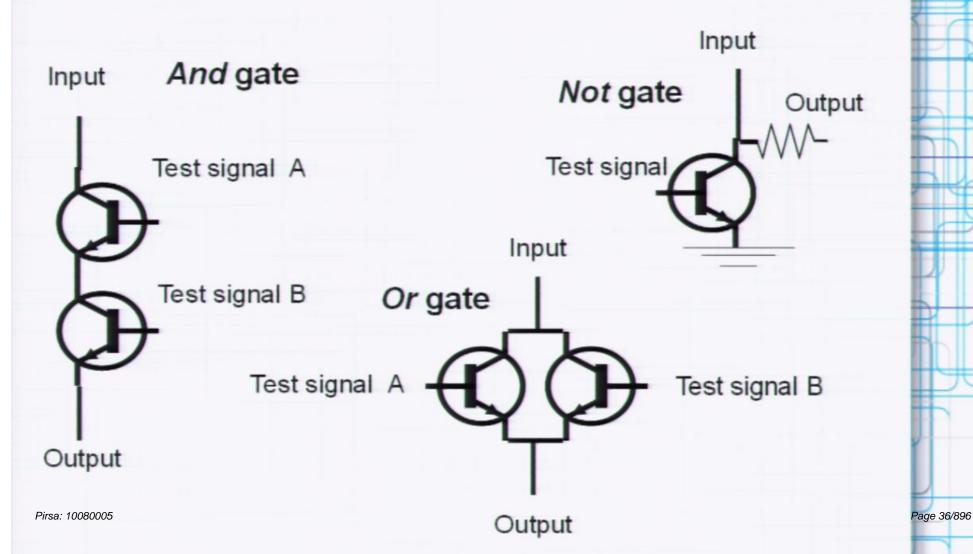
Amplified signal



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How to use them Logic gates

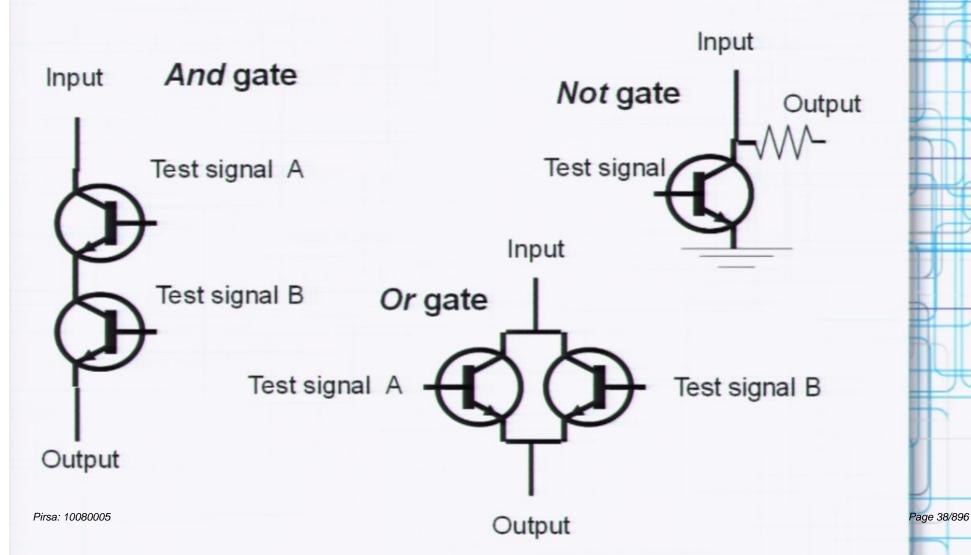


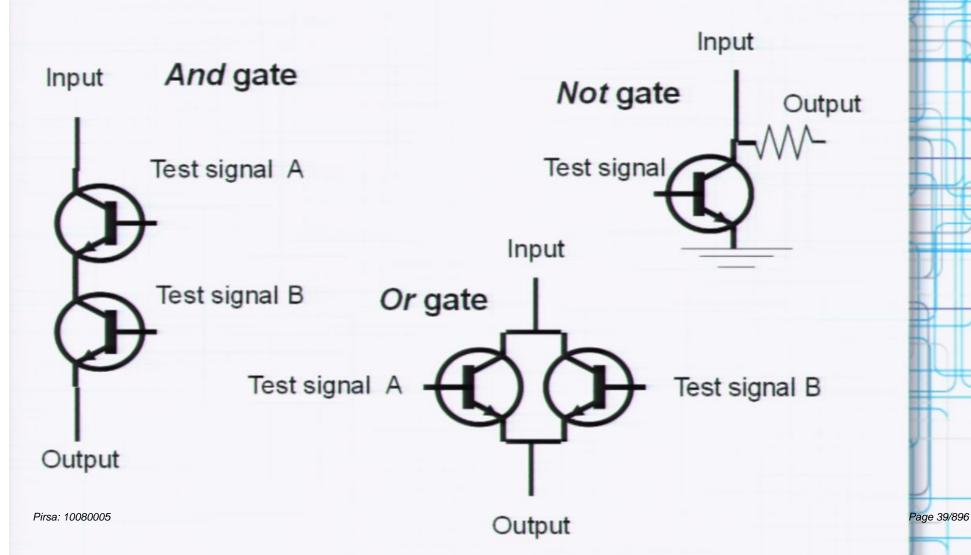
Conclusion

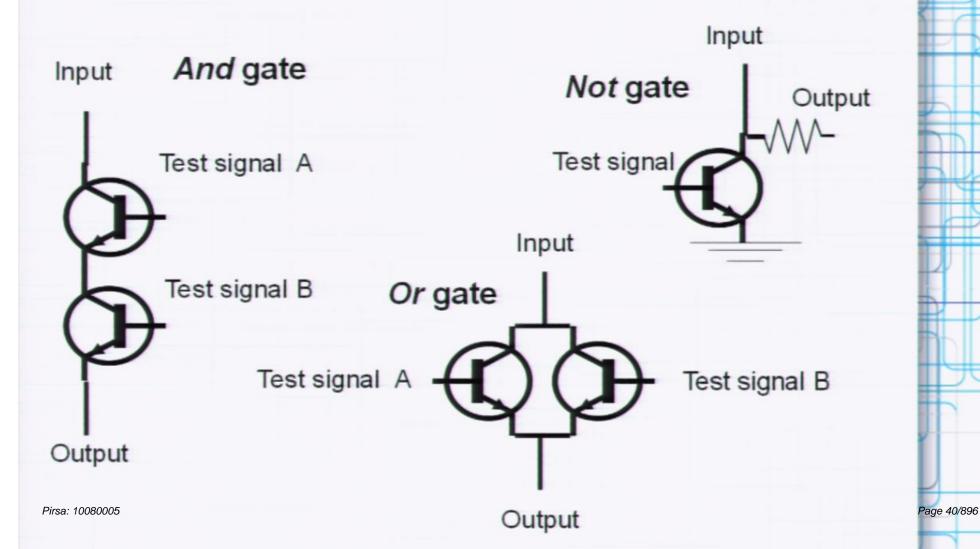
- Important application of solid state physics
- Allows amplification of signals
- Useful device for logic and computation

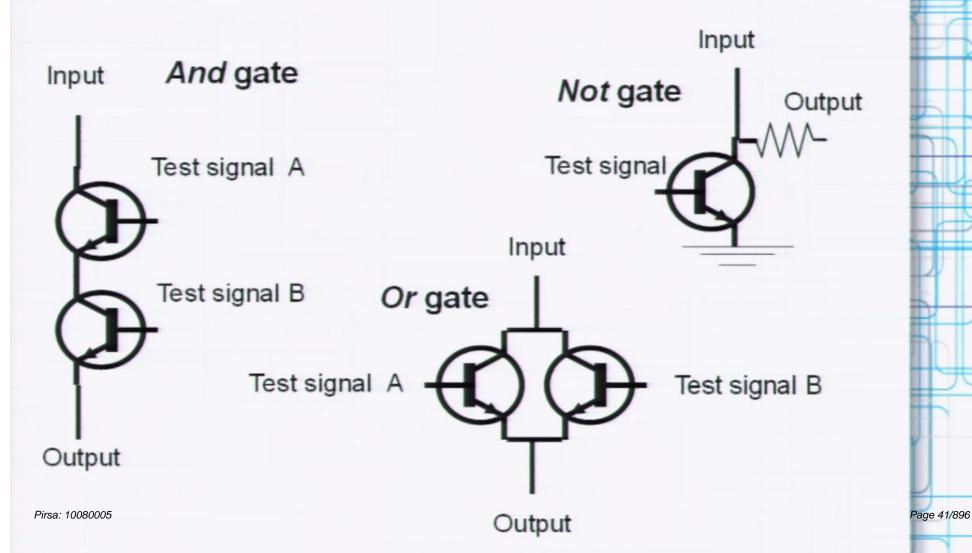
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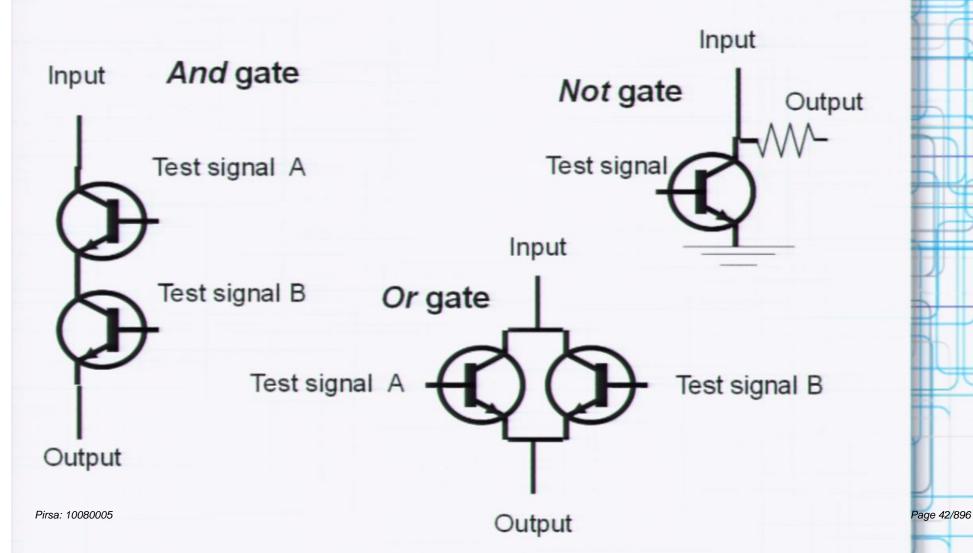
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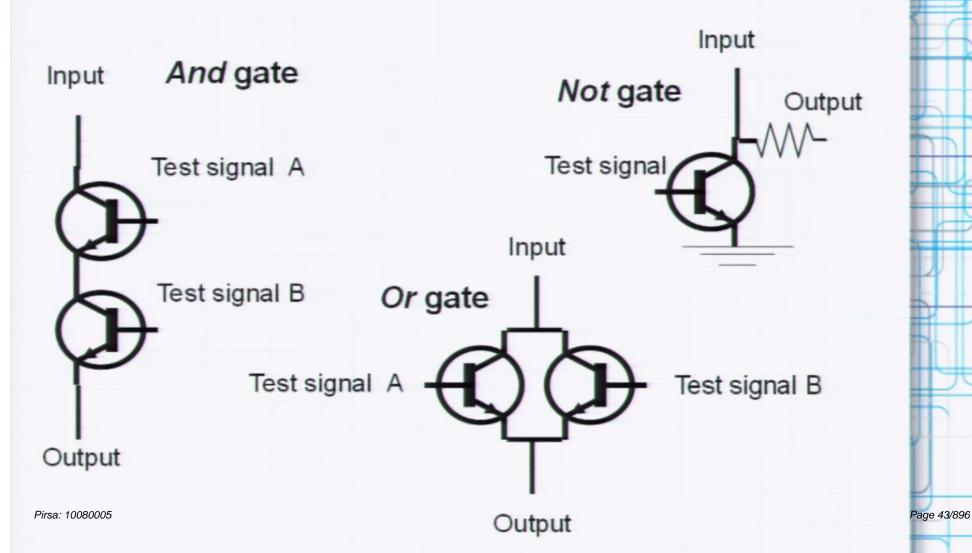












Conclusion

- Important application of solid state physics
- Allows amplification of signals
- Useful device for logic and computation

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Conclusion

- Important application of solid state physics
- Allows amplification of signals
- Useful device for logic and computation

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How to use them

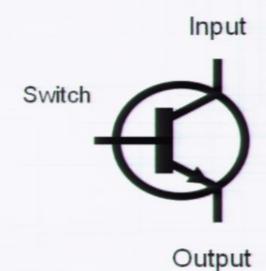
Amplification

On/Off switch

Power source

Small signal

Amplified signal



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Conclusion

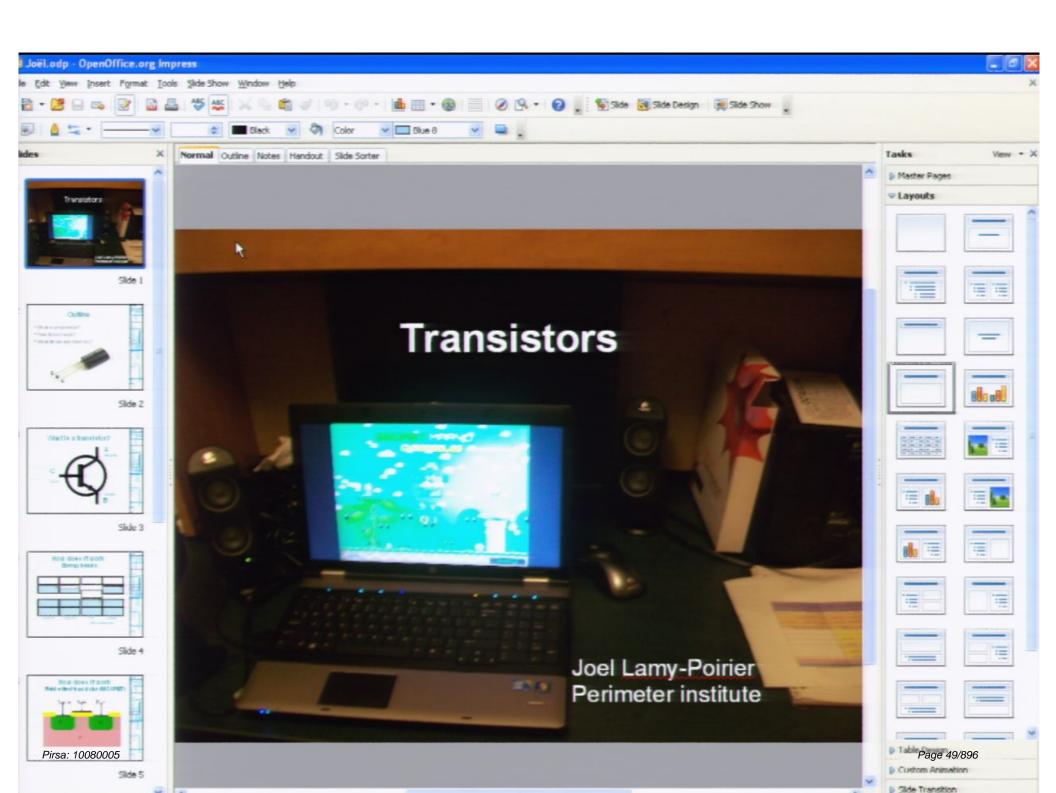
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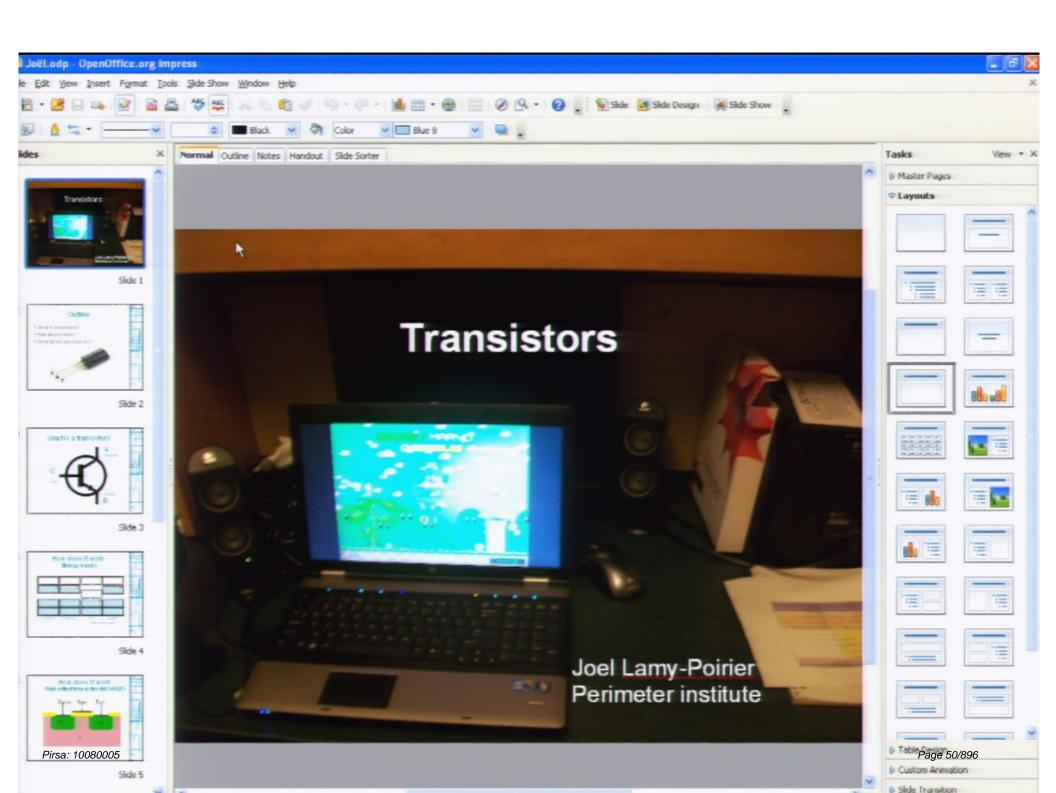
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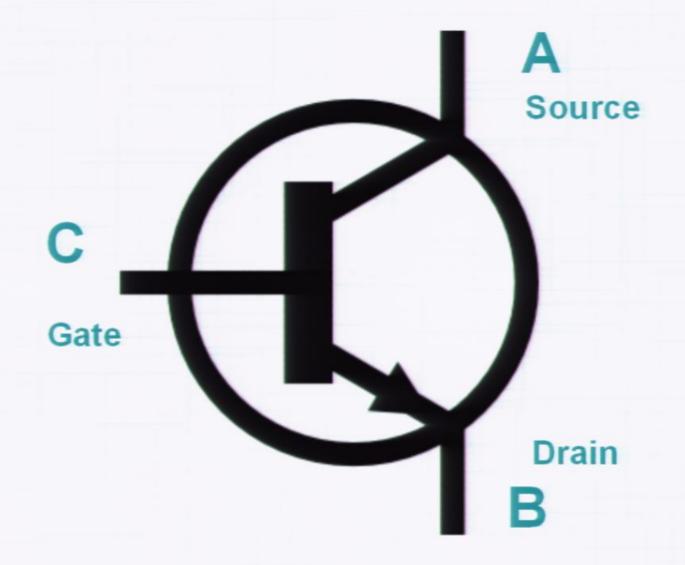
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What is a transistor?



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How to use them

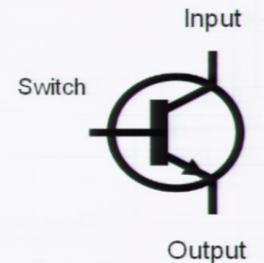
Amplification

On/Off switch

Power source

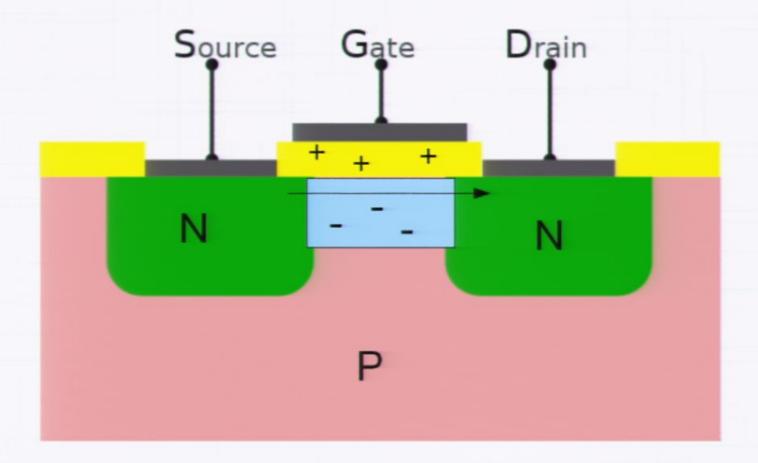


Amplified signal



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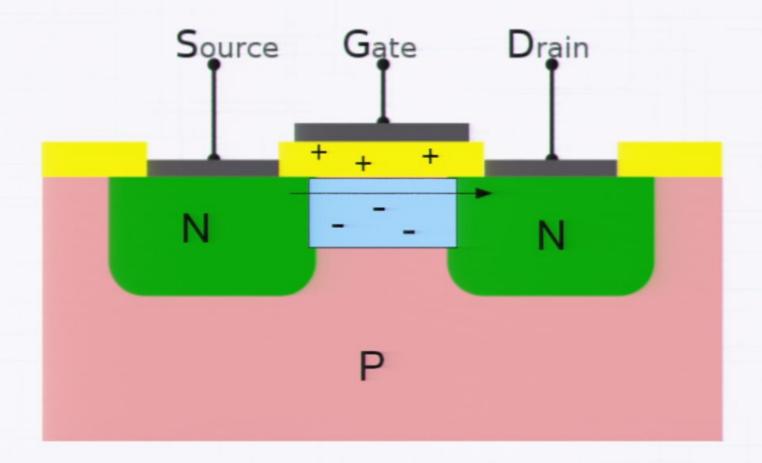
How does it work Field effect transistor (MOSFET)



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How does it work Field effect transistor (MOSFET)



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How to use them

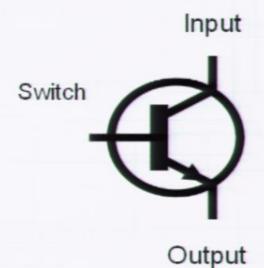
Amplification

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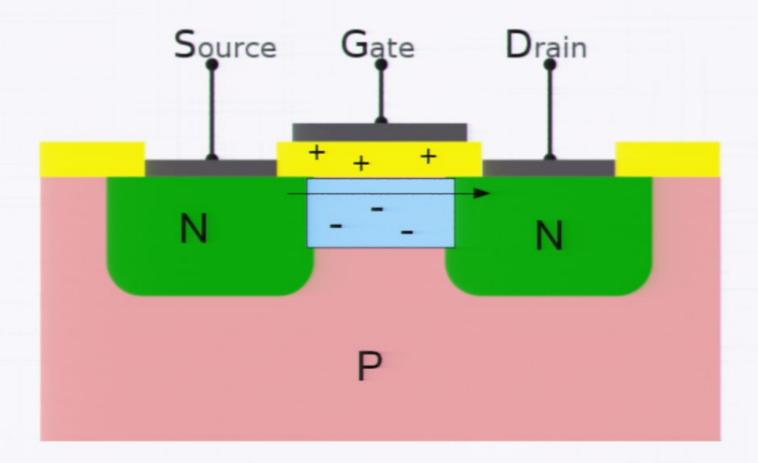
Amplified signal



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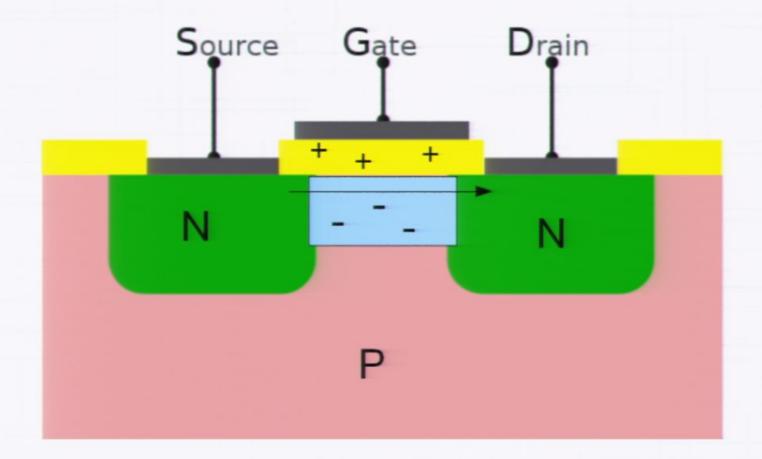
How does it work Field effect transistor (MOSFET)



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Field Exten v does it work So to Slide v t transistor (MOSFET) End Show



How to use them

D

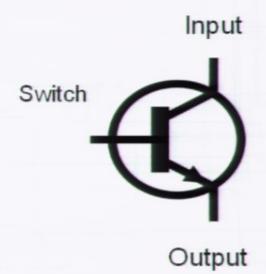
Amplification

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Power source

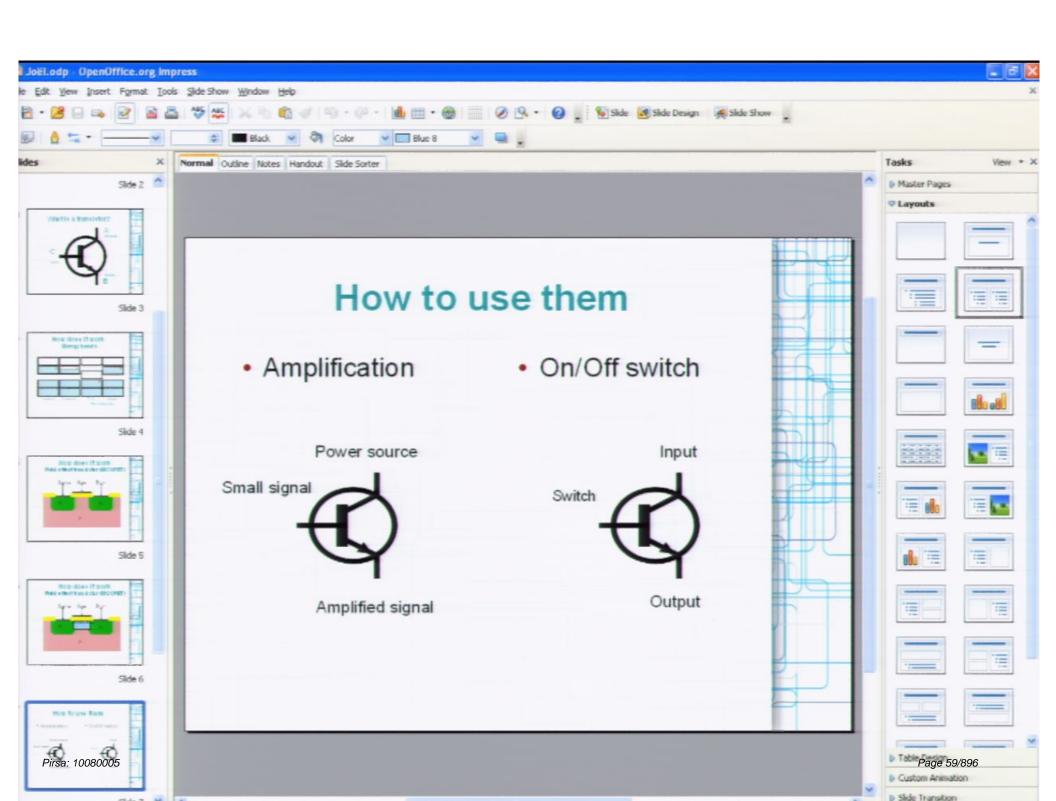


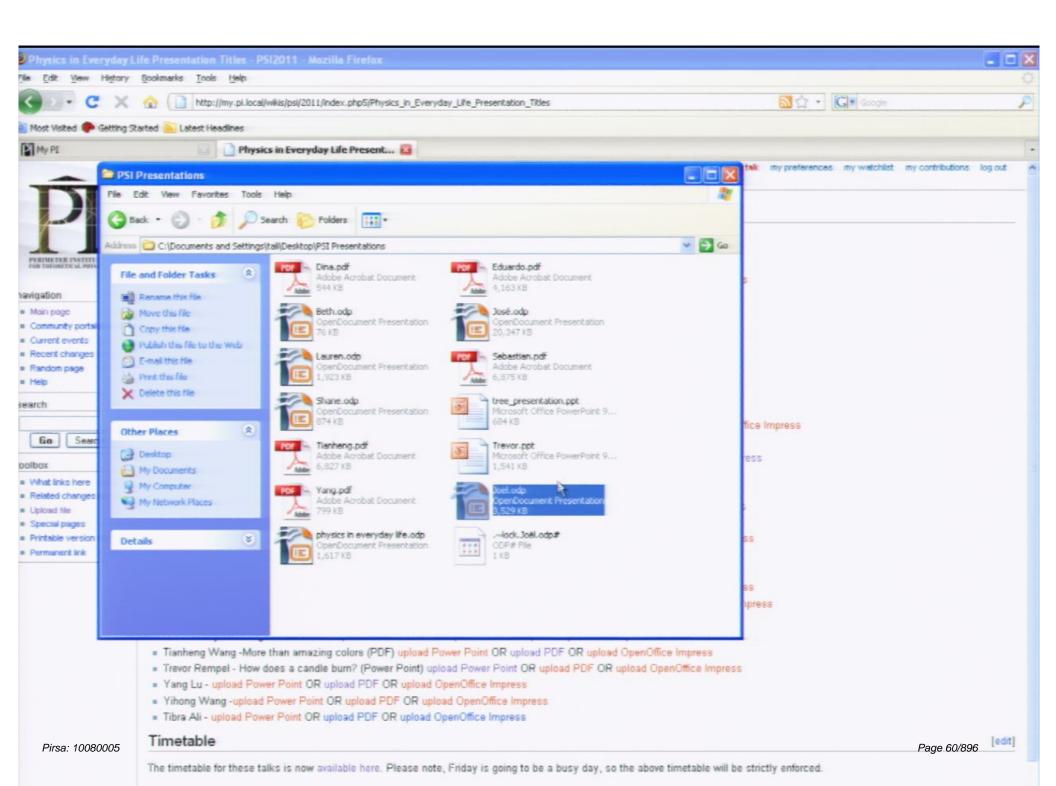
Amplified signal

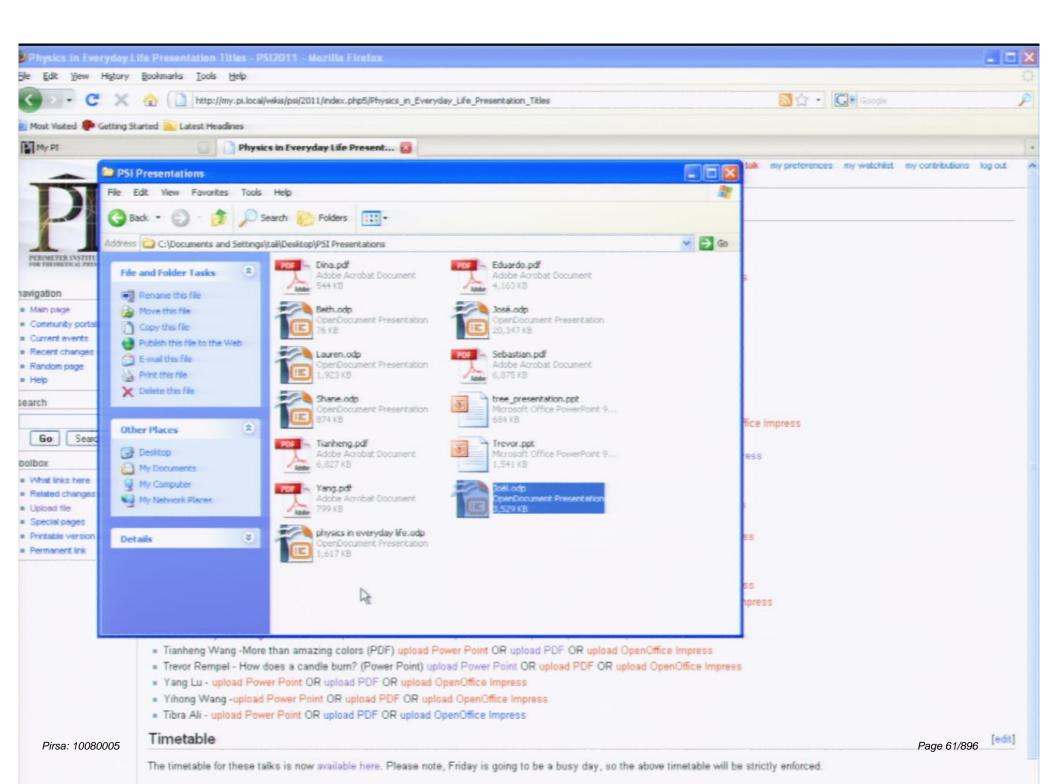


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- Colorful Nature
 - Amazing Colors in Nature
 - Microstructure of Opal
- 2 Creative Human
 - Concept of Photonic Crystal
 - Design Your Photonic Crystal
 - Unexpected New Phenomena

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Photonic Crystal, More Than Amazing Colors

Tianheng Wang

August 20, 2010

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Photonic Crystal, More Than Amazing Colors

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August 20, 2010

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Amazing Colors in Nature Microstructure of Opal

Amazing Colors in Nature

Opal



Taken by me Not attractive at all

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Opal



Taken by me Not attractive at all

Precious Opal



Shining stone

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Opal



Taken by me Not attractive at all

Precious Opal



Shining stone



Cute creature

Opal



Taken by me Not attractive at all

Precious Opal





Cute creature

Opal



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Precious Opal



Shining stone



Cute creature

Opal



Taken by me Not attractive at all

Precious Opal



Shining stone



Cute creature

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Precious Opal

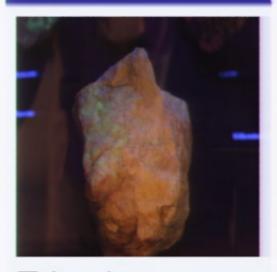


Shining stone



Cute creature

Opal

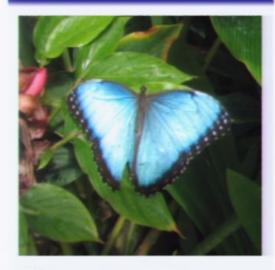


Taken by me Not attractive at all

Precious Opal

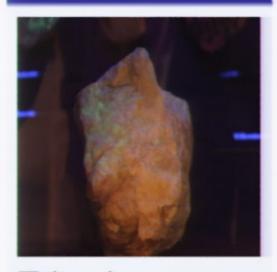


Shining stone



Cute creature

Opal



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Precious Opal

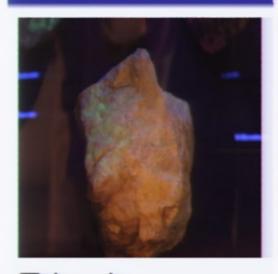


Shining stone



Cute creature

Opal



Taken by me Not attractive at all

Precious Opal



Shining stone



Cute creature

Opal



Taken by me Not attractive at all

Precious Opal



Shining stone



Cute creature

Opal



Taken by me Not attractive at all

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Shining stone



Cute creature

Opal



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Shining stone



Cute creature

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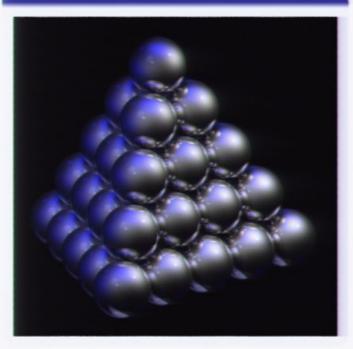


Shining stone



Cute creature

Microstructure of Precious Opal

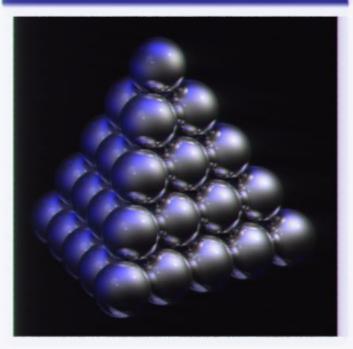


Spheres of sillica of fairly regular size

Hexagonal or cubic close-packed lattice

Variable interplay of internal colors

Microstructure of Precious Opal



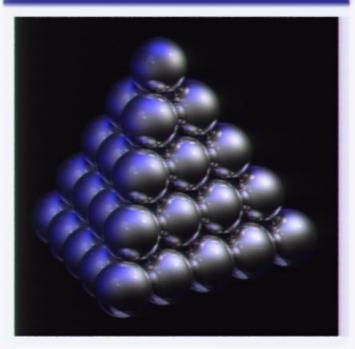
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Microstructure of Precious Opal

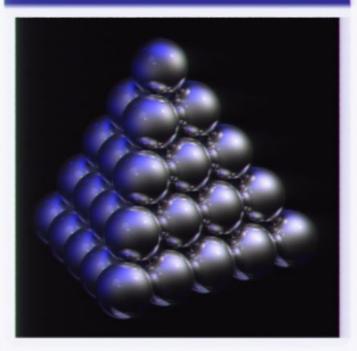


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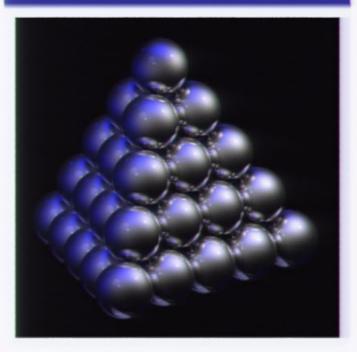


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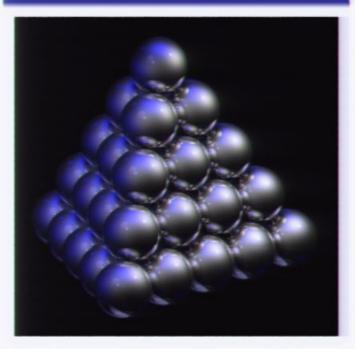


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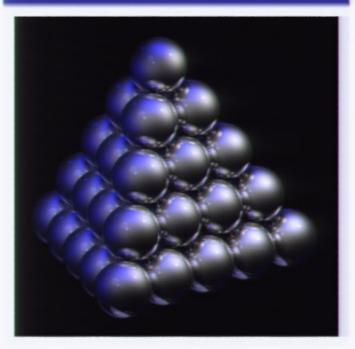


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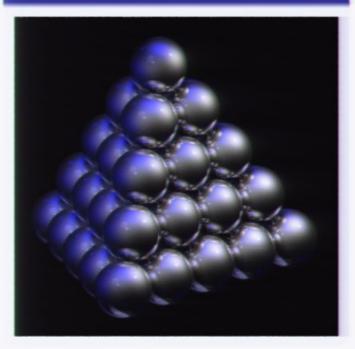


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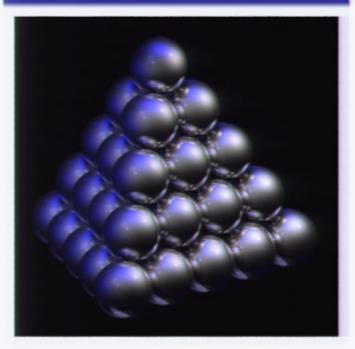


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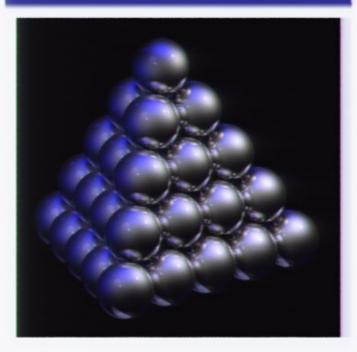


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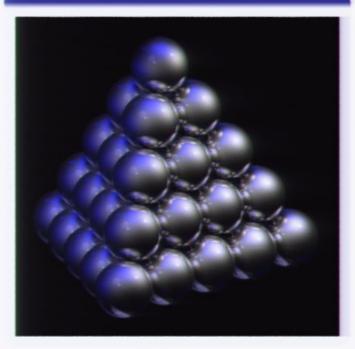


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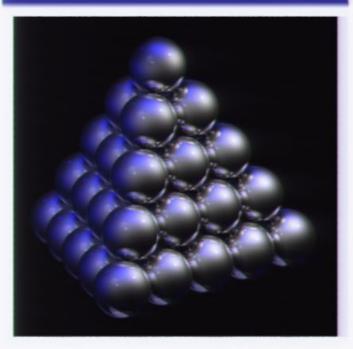


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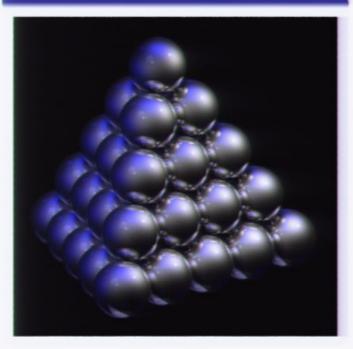
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Microstructure of Precious Opal



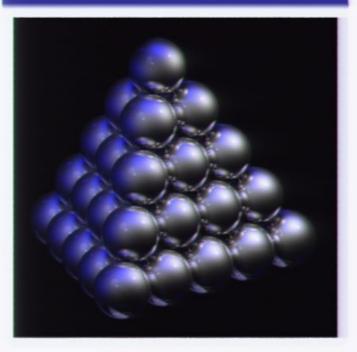
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Microstructure of Precious Opal

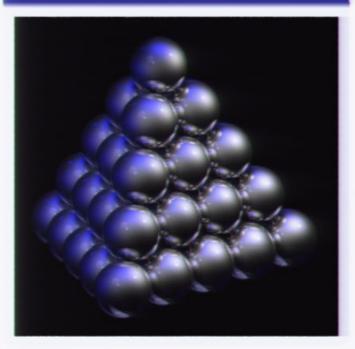


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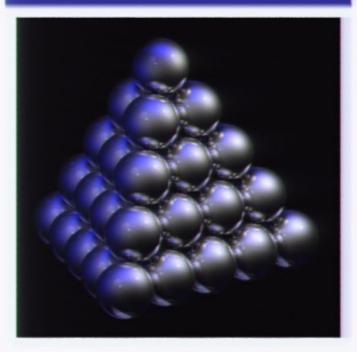


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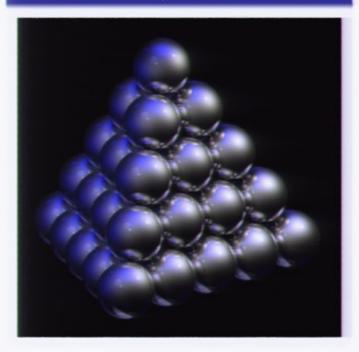


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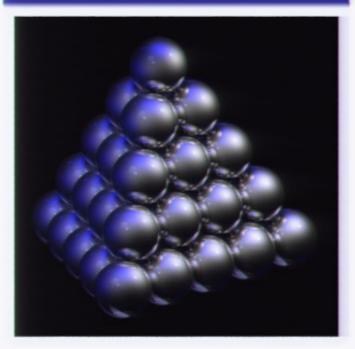


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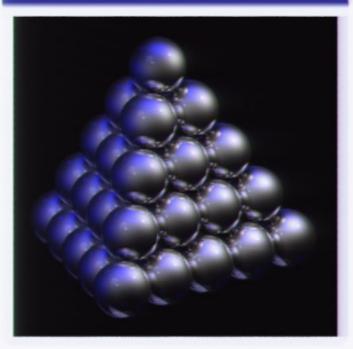


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Variable interplay of internal colors

Microstructure of Precious Opal

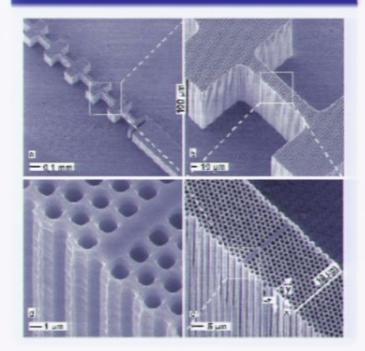


Spheres of sillica of fairly regular size

Hexagonal or cubic close-packed lattice

Variable interplay of internal colors

Microstructure

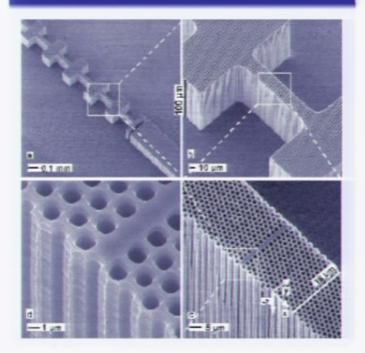


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 99/896

Microstructure

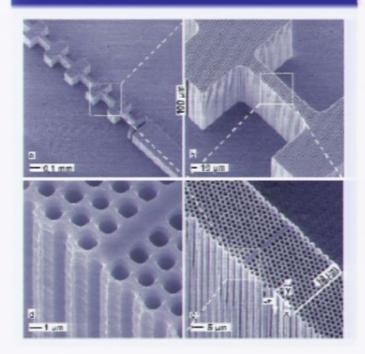


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 100/896

Microstructure

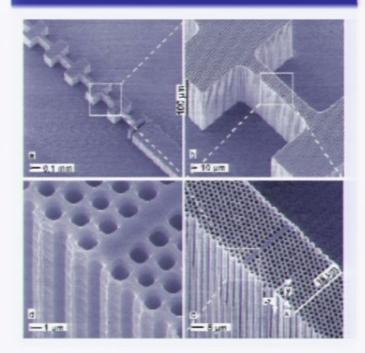


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 101/896

Microstructure

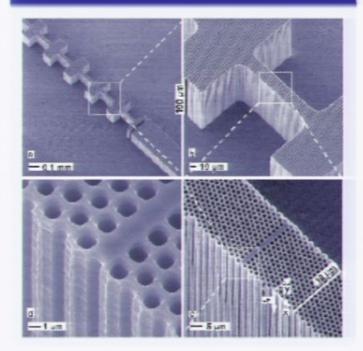


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 102/896

Microstructure

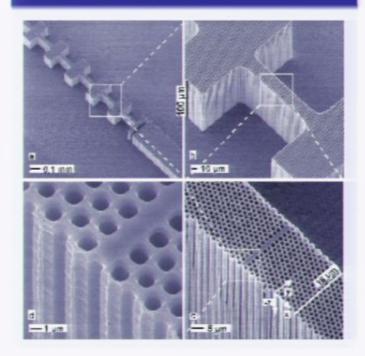


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 103/896

Microstructure

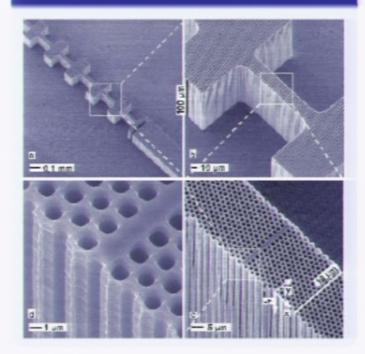


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 104/896

Microstructure

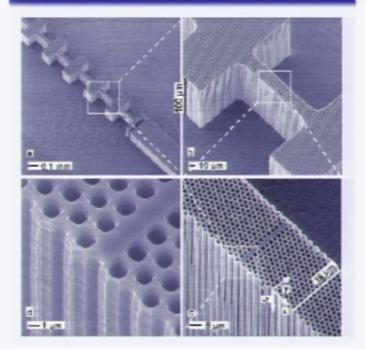


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 105/896

Microstructure

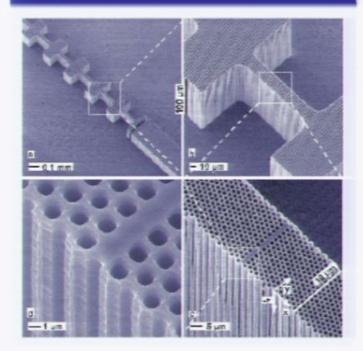


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 106/896

Microstructure

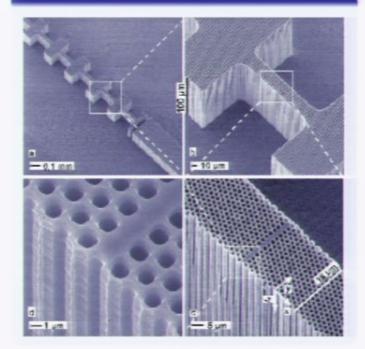


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 107/896

Microstructure

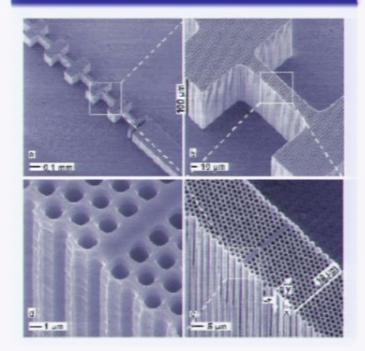


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 108/896

Microstructure

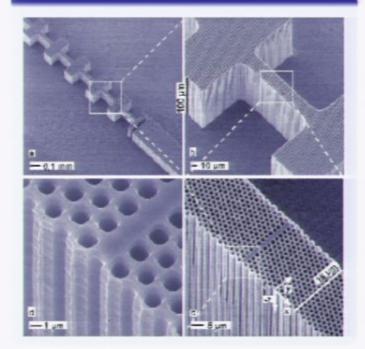


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 109/896

Microstructure

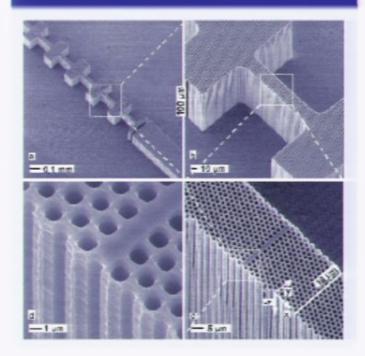


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 110/896

Microstructure

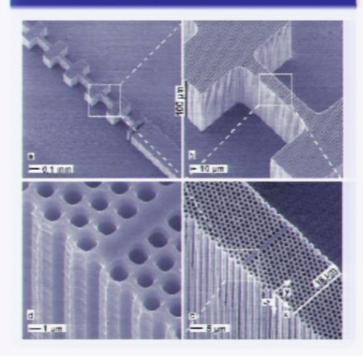


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 111/896

Microstructure

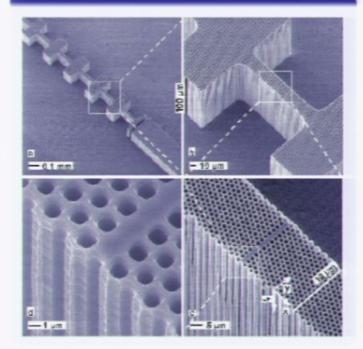


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 112/896

Microstructure

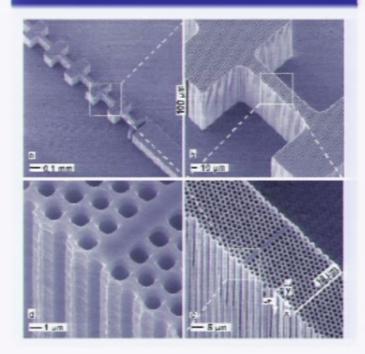


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 113/896

Microstructure

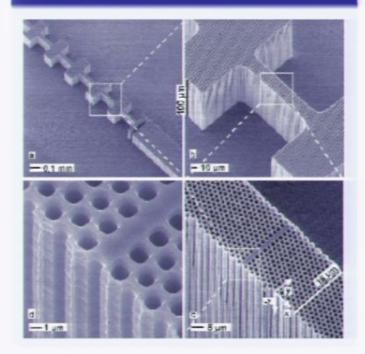


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 114/896

Microstructure

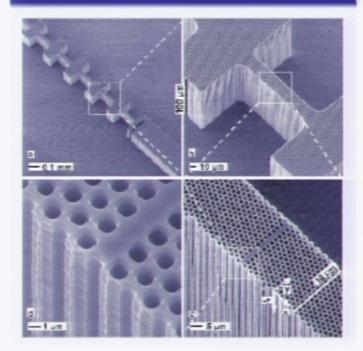


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 115/896

Microstructure

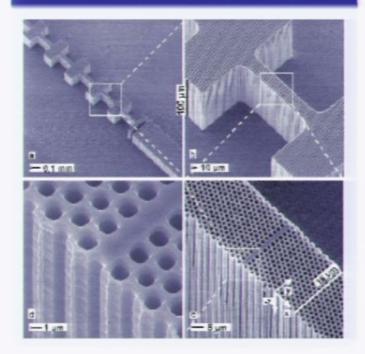


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 116/896

Microstructure

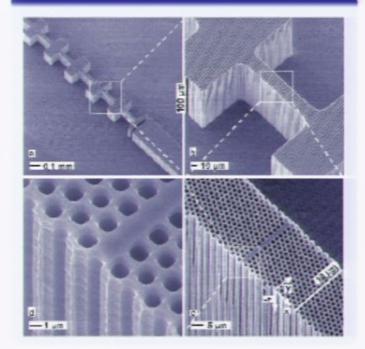


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 117/896

Microstructure

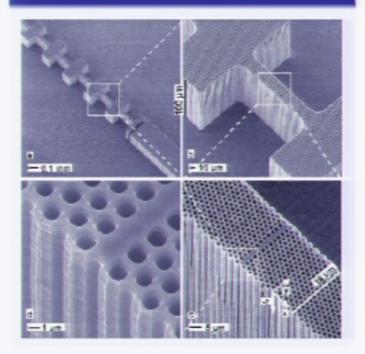


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 118/896

Microstructure

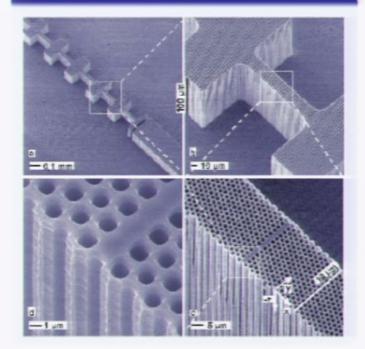


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 119/896

Microstructure

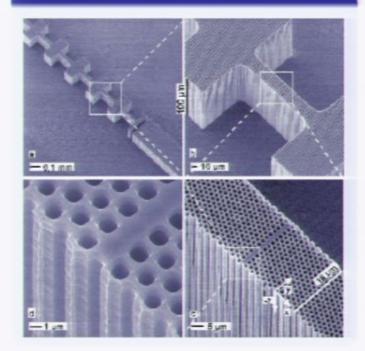


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

Pirsa: 10080005 Page 120/896

Microstructure



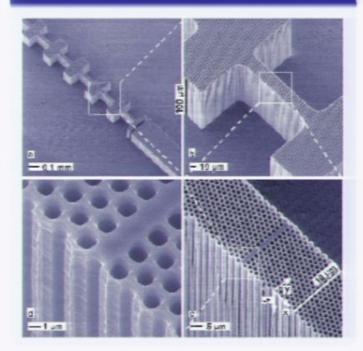
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 121/896

Microstructure



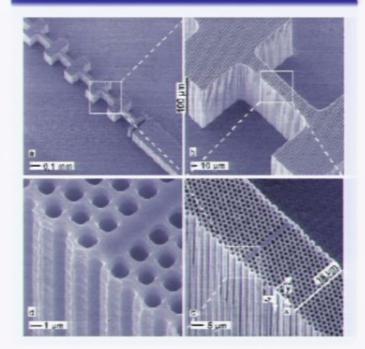
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 122/896

Microstructure



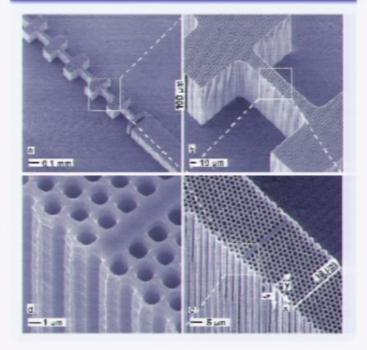
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 123/896

Microstructure



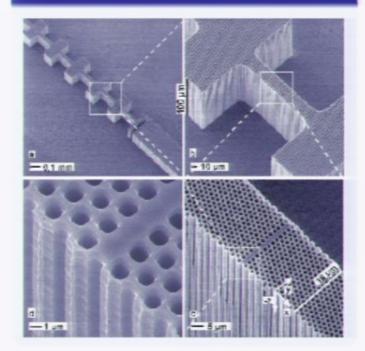
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 124/896

Microstructure



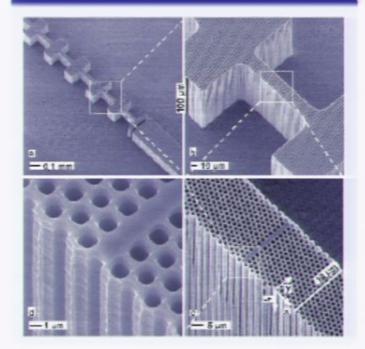
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 125/896

Microstructure



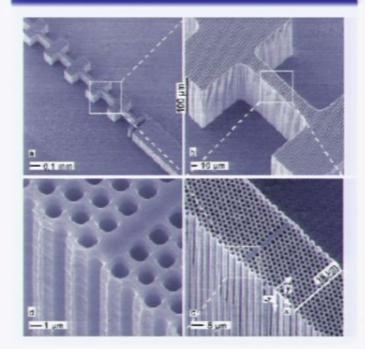
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 126/896

Microstructure

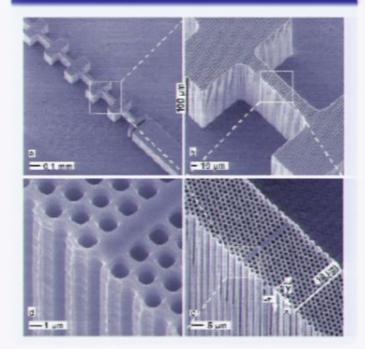


Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Microstructure



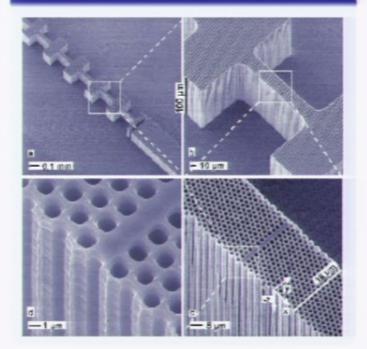
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 128/896

Microstructure



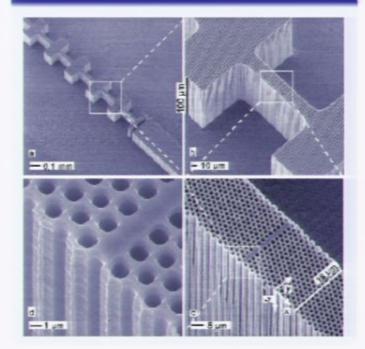
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 129/896

Microstructure



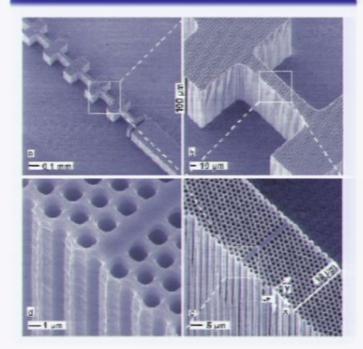
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 130/896

Microstructure



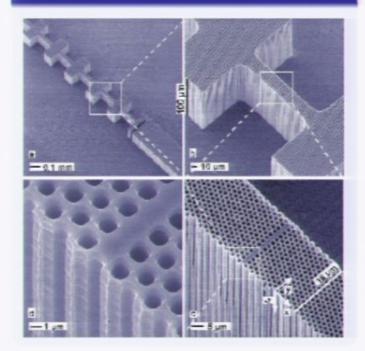
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 131/896

Microstructure



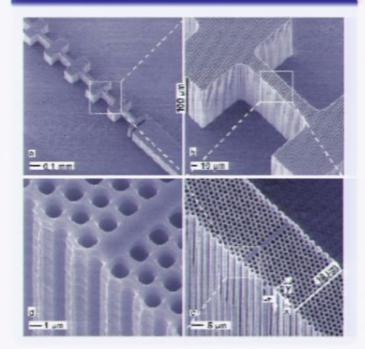
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 132/896

Microstructure



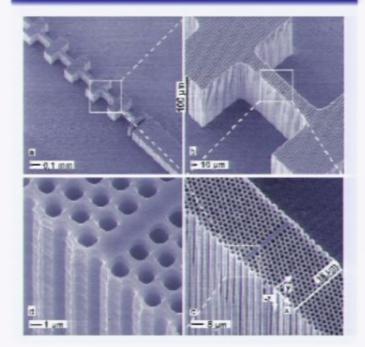
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 133/896

Microstructure



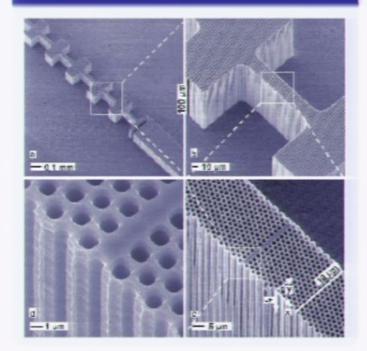
Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

Pirsa: 10080005 Page 134/896

Microstructure



Concept of Photonic Crystal

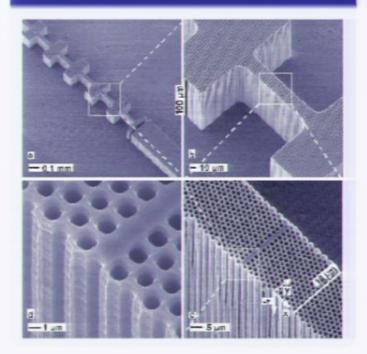
crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

similar to semiconductors

able to provide complete tunability

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Microstructure



Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

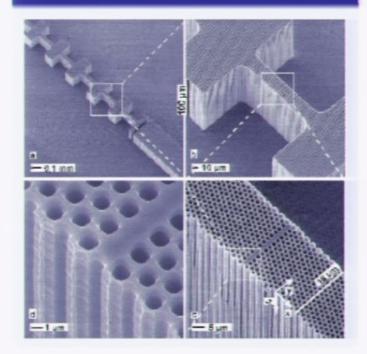
similar to semiconductors

able to provide complete tunability

Essential Property

Regularly repeating internal regions 136/896

Microstructure



Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

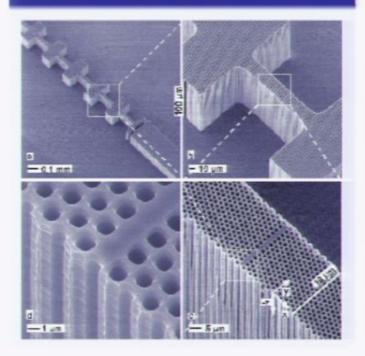
similar to semiconductors

able to provide complete tunability

Essential Property

Regularly repeating internal regions 137/896

Microstructure



Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

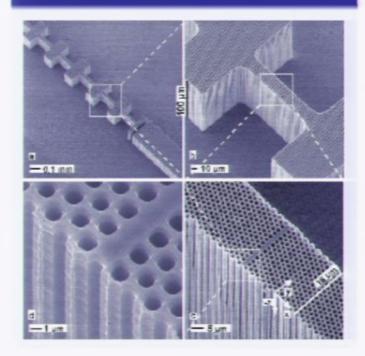
similar to semiconductors

able to provide complete tunability

Essential Property

Regularly repeating internal regions 138/896

Microstructure



Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

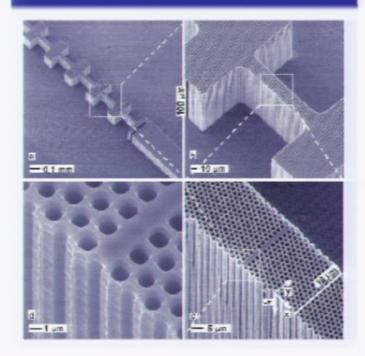
similar to semiconductors

able to provide complete tunability

Essential Property

Regularly repeating internal regions 139/896

Microstructure



Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

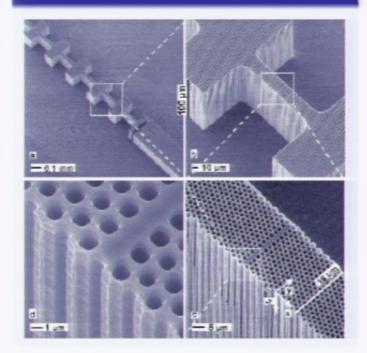
similar to semiconductors

able to provide complete tunability

Essential Property

Regularly repeating internal regions 140/896

Microstructure



Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

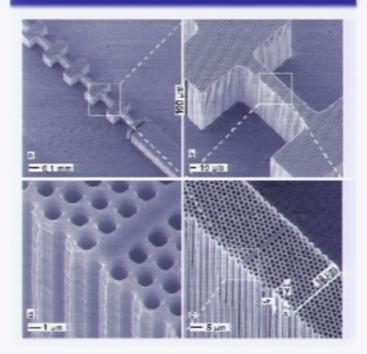
similar to semiconductors

able to provide complete tunability

Essential Property

Regularly repeating internal regions 141/896

Microstructure



Concept of Photonic Crystal

crystals which are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of photons

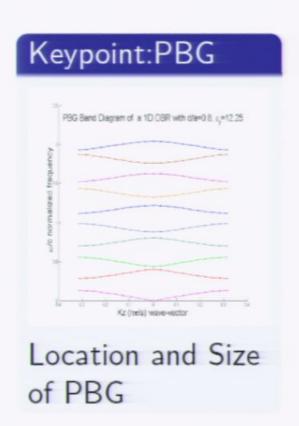
similar to semiconductors

able to provide complete tunability

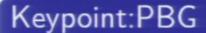
Essential Property

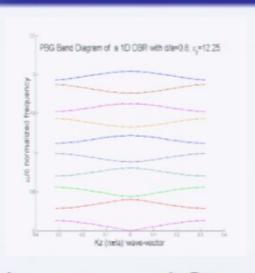
Regularly repeating internal regions 142/896

Design Your Photonic Crystal



Design Your Photonic Crystal





Location and Size of PBG

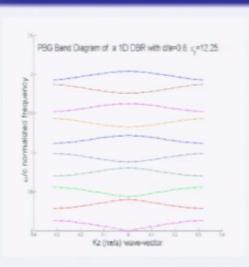
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method





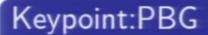
Location and Size of PBG

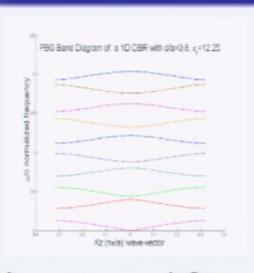
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method





Location and Size of PBG

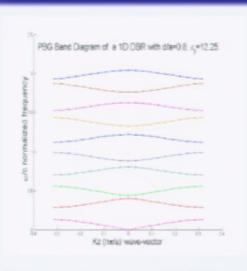
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method





Location and Size of PBG

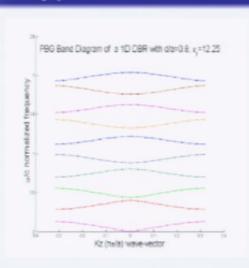
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method





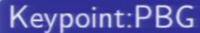
Location and Size of PBG

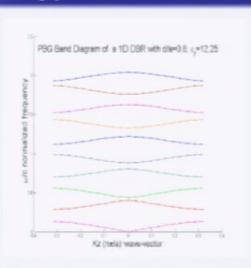
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method





Location and Size of PBG

Computational Methods

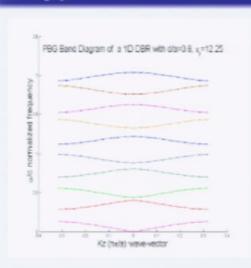
Plane Wave Expansion

Methods

Finite Difference Time Domain

Order-N Spectral Method





Location and Size of PBG

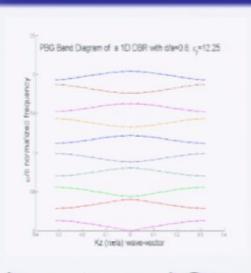
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method





Location and Size of PBG

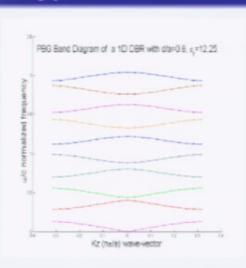
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method





Location and Size of PBG

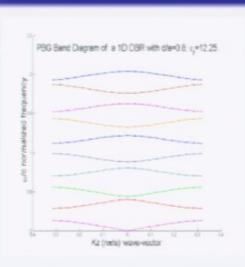
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method





Location and Size of PBG

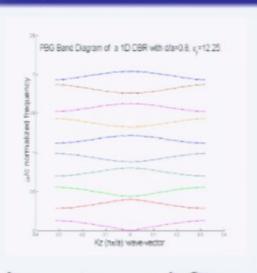
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method

Keypoint:PBG



Location and Size of PBG

Computational Methods

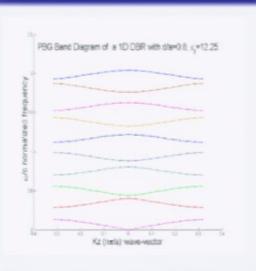
Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method

Pirsa: 10080005





Location and Size of PBG

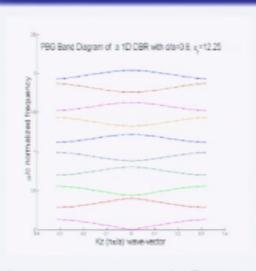
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method





Location and Size of PBG

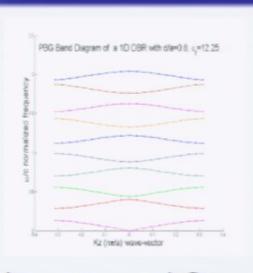
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method





Location and Size of PBG

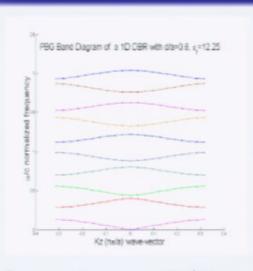
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method





Location and Size of PBG

Computational Methods

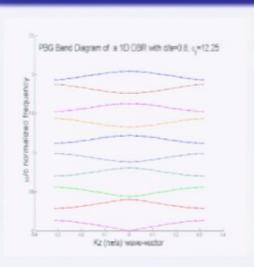
Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method

Pirsa: 10080005





Location and Size of PBG

Computational Methods

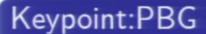
Plane Wave Expansion

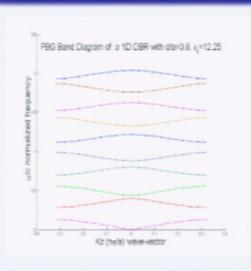
Methods

Finite Difference Time Domain

Order-N Spectral Method

Pirsa: 10080005





Location and Size of PBG

Computational Methods

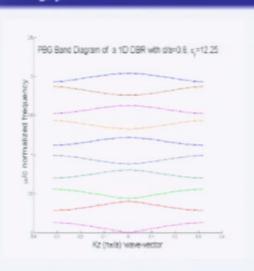
Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method

Pirsa: 10080005

Keypoint:PBG



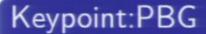
Location and Size of PBG

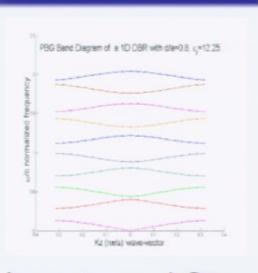
Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

Order-N Spectral Method





Location and Size of PBG

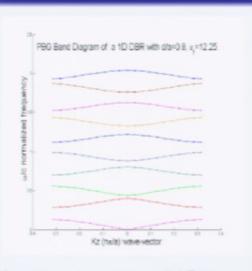
Computational Methods

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Finite Difference Time Domain

Order-N Spectral Method

Keypoint:PBG



Location and Size of PBG

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Finite Difference Time Domain

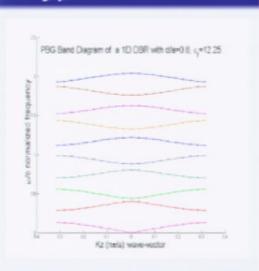
Order-N Spectral Method

Applications

Photonic-crystal Fibre—Commercial

3-D Photonic Crystal—Research, Optical computer

Keypoint:PBG



Location and Size of PBG

Computational Methods

Plane Wave Expansion Methods

Finite Difference Time Domain

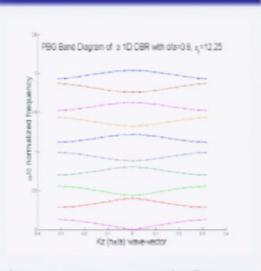
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Keypoint:PBG



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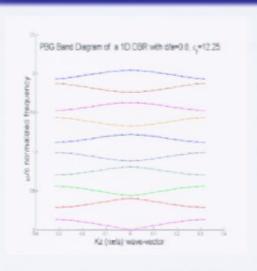
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Photonic-crystal Fibre—Commercial

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Keypoint:PBG



Location and Size of PBG

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Plane Wave Expansion Methods

Finite Difference Time Domain

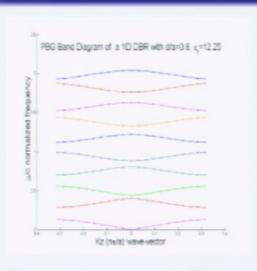
Order-N Spectral Method

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Keypoint:PBG



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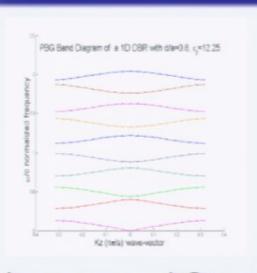
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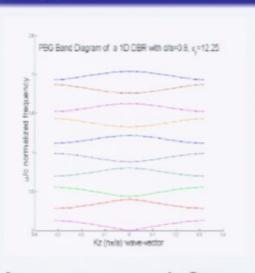
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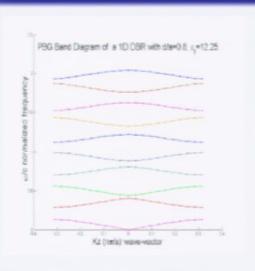
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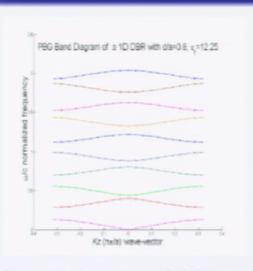
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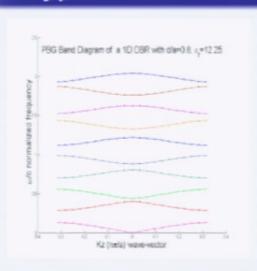
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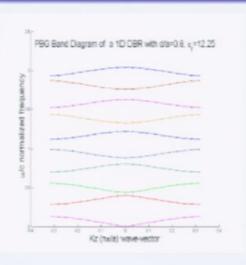
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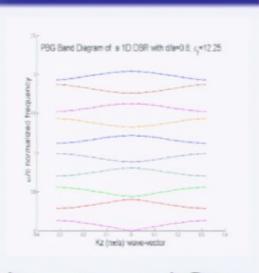
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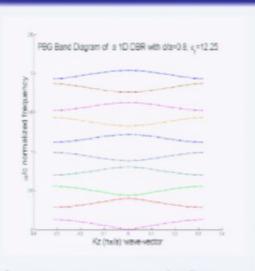
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Location and Size of PBG

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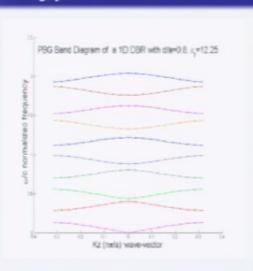
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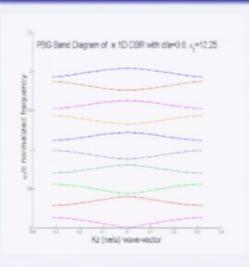
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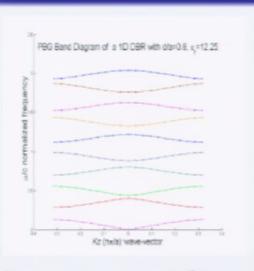
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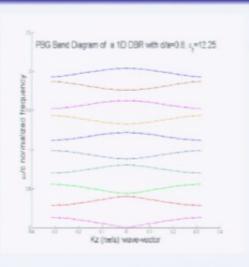
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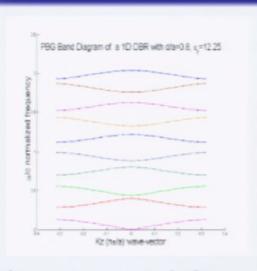
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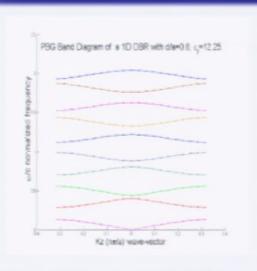
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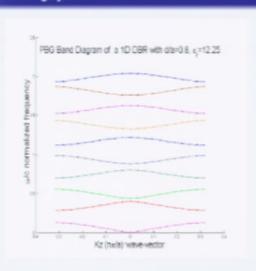
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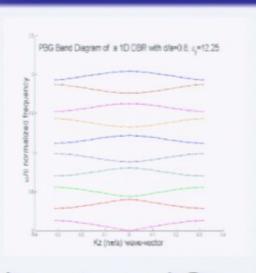
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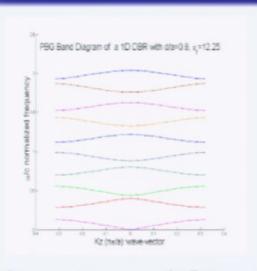
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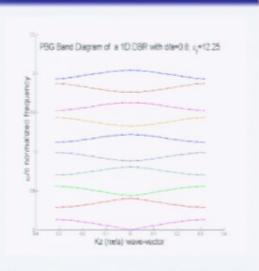
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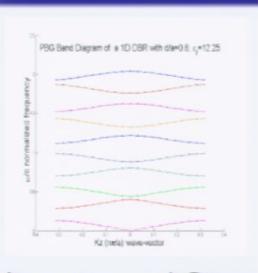
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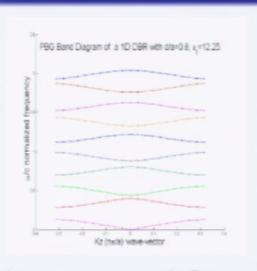
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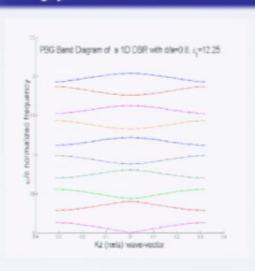
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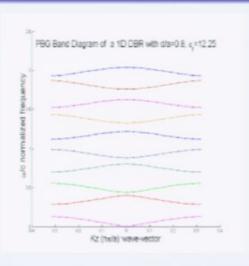
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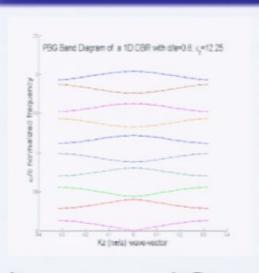
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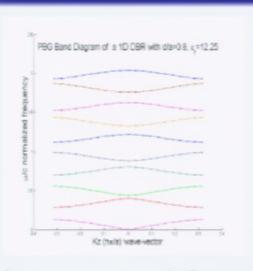
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Concept of Photonic Crystal Design Your Photonic Crystal Unexpected New Phenomena

Shock Wave in a Photonic Crystal

Computational experiment performed by Evan J.Reed, Marin Soljacic and John D.Joannopoulos.

Shock Wave

A type of propagation of disturbance

Carries energy through a medium

Pirsa: 10080005 Page 192/896

Concept of Photonic Crystal Design Your Photonic Crystal Unexpected New Phenomena

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Shock Wave Model

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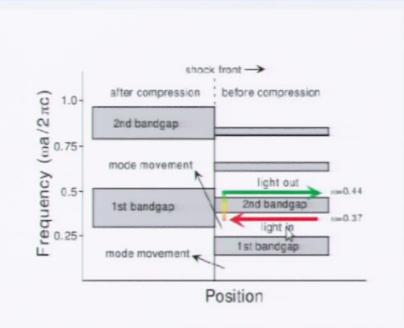
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Shock Wave Model

$$\epsilon(\hat{x} = \frac{x}{a}, \hat{t} = \frac{ct}{a}) = 7 + 6\sin[\pi(3\hat{x} - \frac{v}{c}\hat{t} - \frac{\pi}{\gamma}\log(2\cosh(\gamma(\hat{x} - \frac{v}{c}\hat{t})))]$$

Frequency - Position

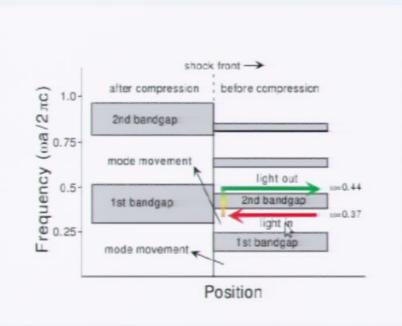


Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Frequency – Position

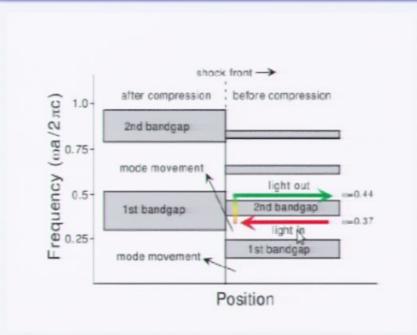


Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Frequency – Position



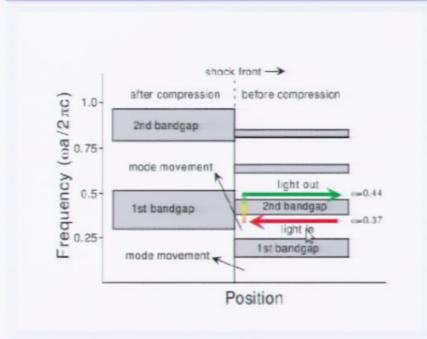
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 222/896

Frequency – Position



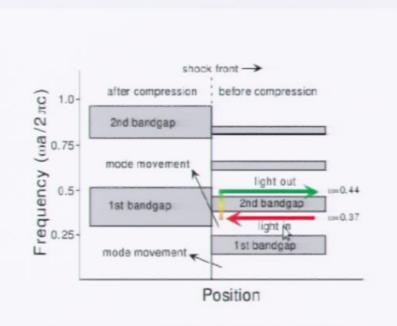
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 223/896

Frequency – Position



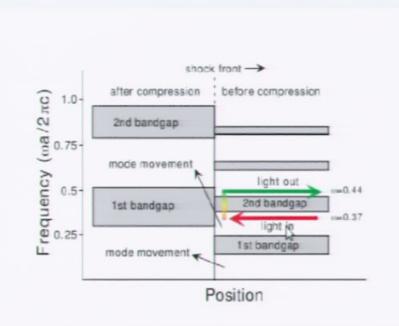
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 224/896

Frequency – Position



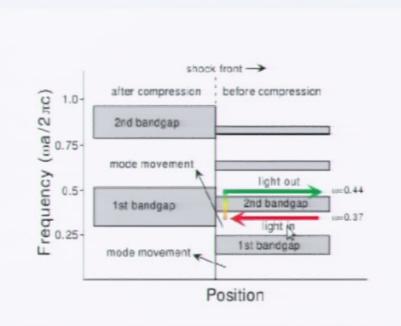
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 225/896

Frequency – Position

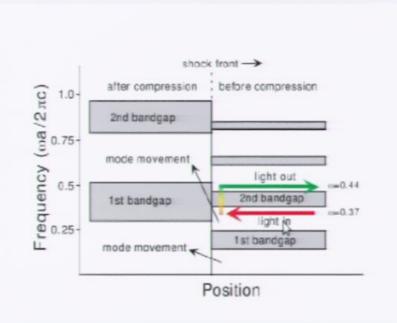


Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Frequency – Position

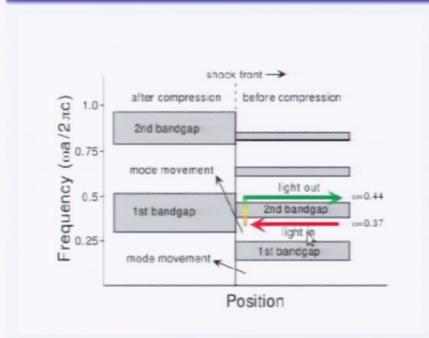


Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Frequency – Position



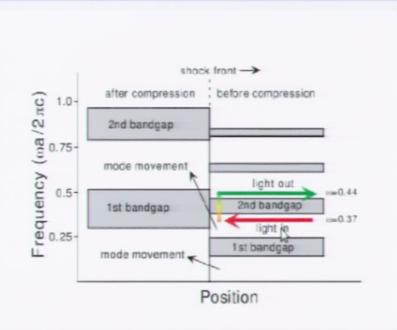
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 228/896

Frequency – Position

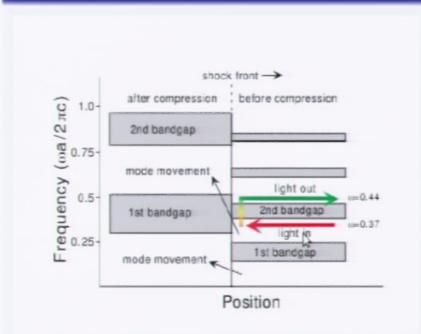


Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Frequency – Position



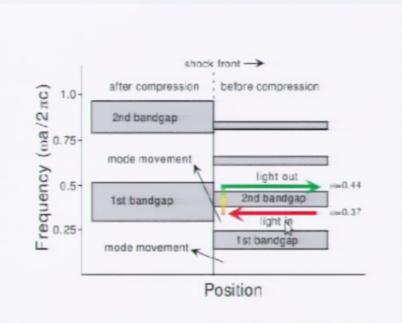
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 230/896

Frequency – Position



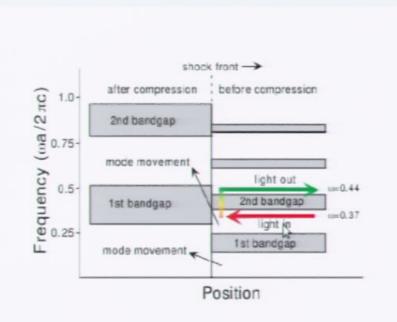
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 231/896

Frequency – Position



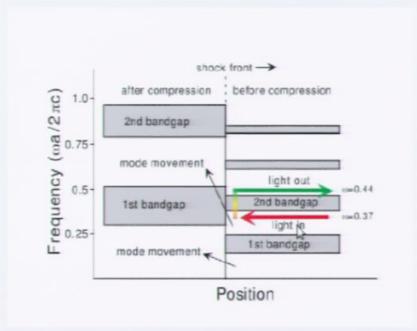
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 232/896

Frequency – Position



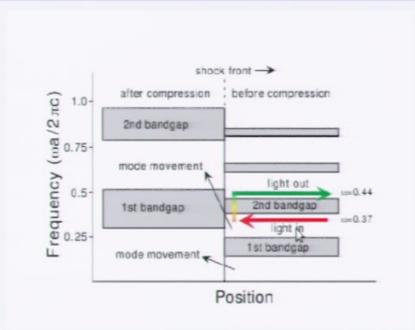
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 233/896

Frequency – Position



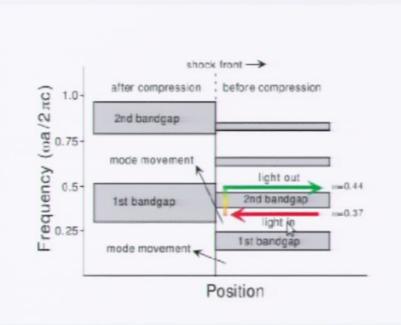
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 234/896

Frequency – Position



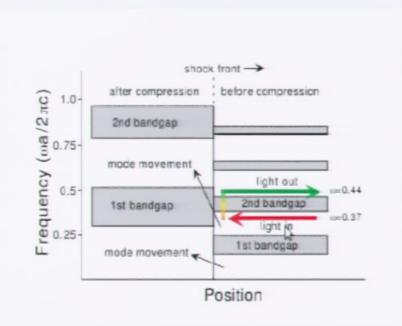
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 235/896

Frequency – Position



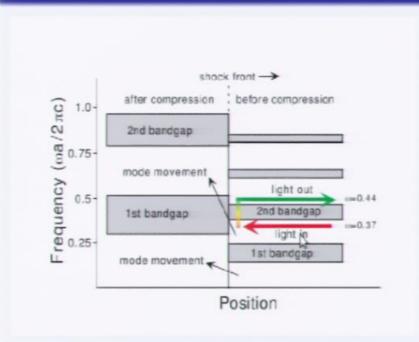
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 236/896

Frequency - Position



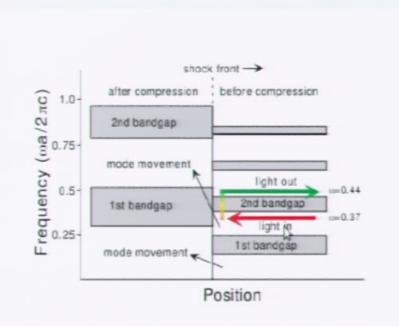
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 237/896

Frequency – Position

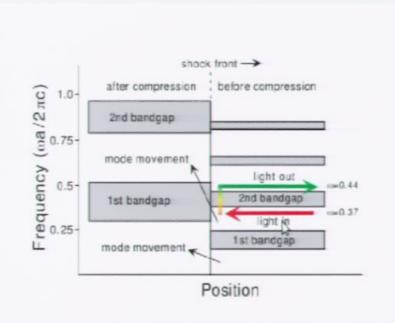


Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Frequency – Position



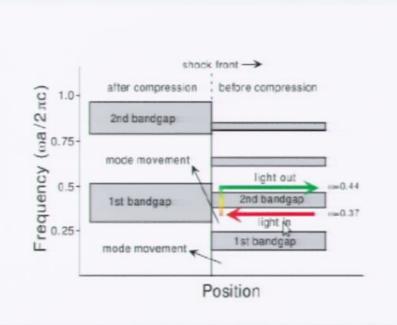
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 239/896

Frequency – Position



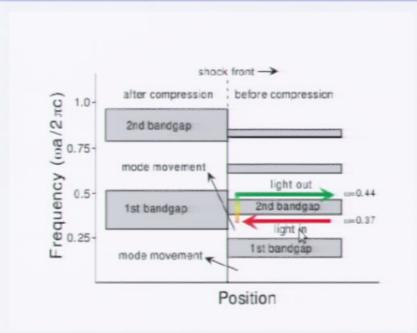
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 240/896

Frequency – Position



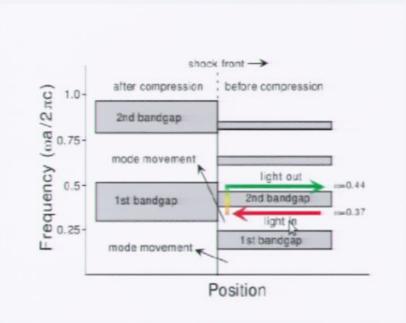
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 241/896

Frequency – Position



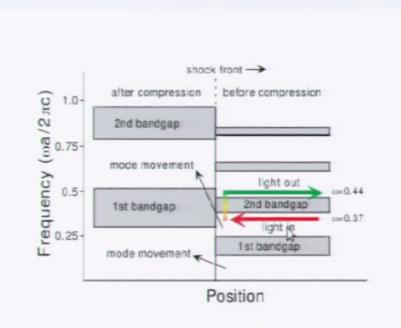
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 242/896

Frequency - Position

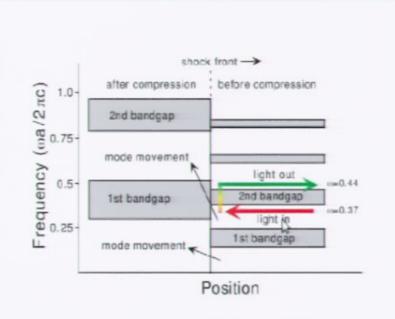


Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Frequency – Position



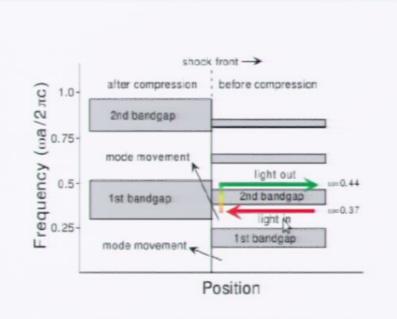
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 244/896

Frequency – Position



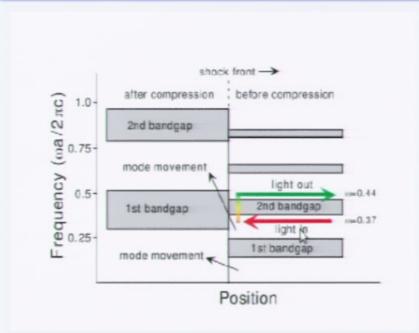
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 245/896

Frequency – Position

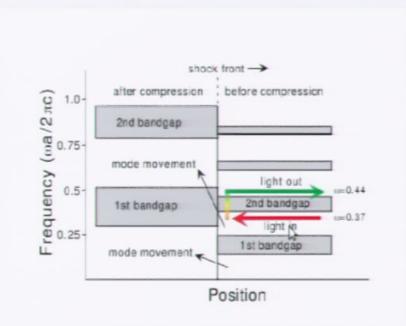


Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Frequency - Position



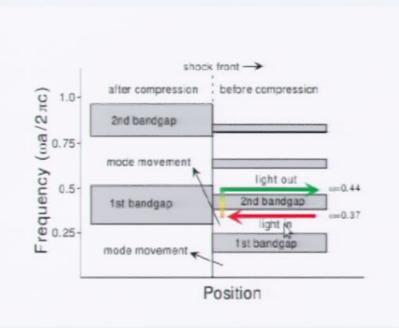
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 247/896

Frequency – Position

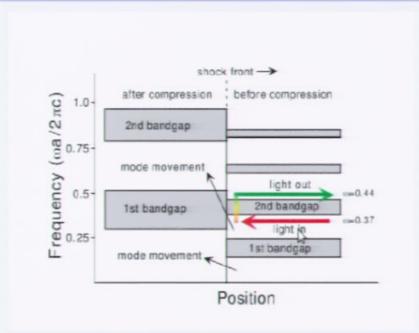


Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Frequency – Position



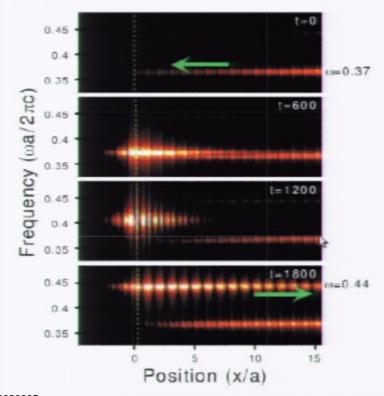
Frequncy Shift

Frequency of light is shifted to the top of the bandgap.

The amount of frequency shift depends on the size of the bandgap of the pre-shocked crystal.

Pirsa: 10080005 Page 249/896

Frequency - Position

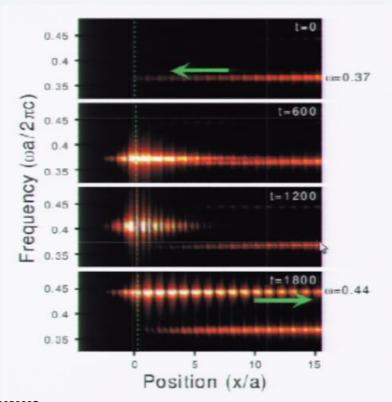


Localization of Light

Light is trapped in a localized state at the shock front in the overlapping bandgap.

In this period, frequency is shifted.

Frequency – Position

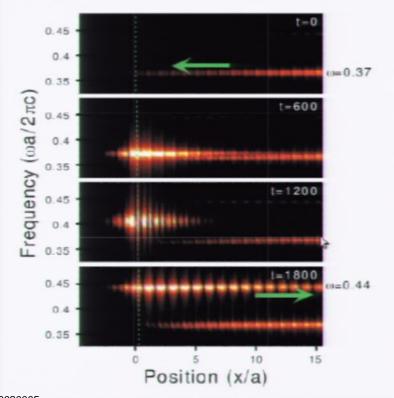


Localization of Light

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In this period, frequency is shifted.

Frequency - Position

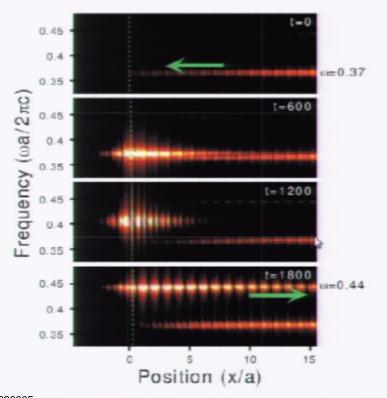


Localization of Light

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In this period, frequency is shifted.

Frequency - Position

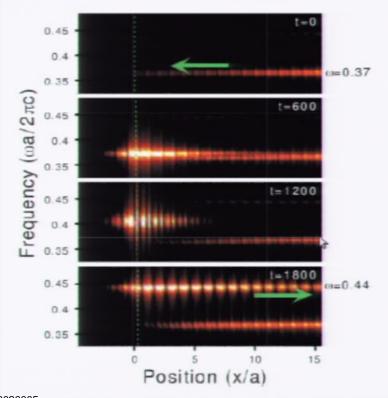


Localization of Light

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In this period, frequency is shifted.

Frequency - Position

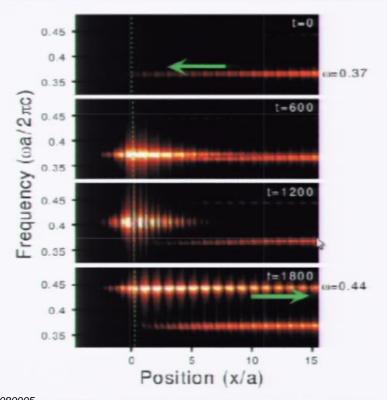


Localization of Light

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In this period, frequency is shifted.

Frequency - Position

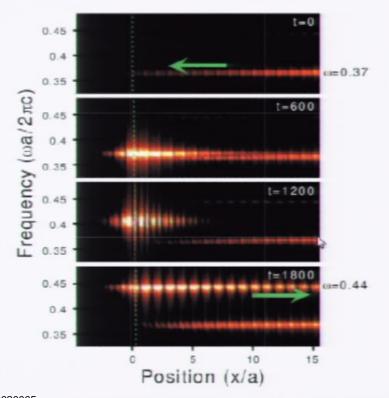


Localization of Light

Light is trapped in a localized state at the shock front in the overlapping bandgap.

In this period, frequency is shifted.

Frequency - Position

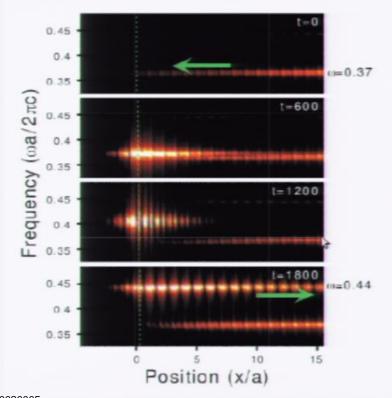


Localization of Light

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In this period, frequency is shifted.

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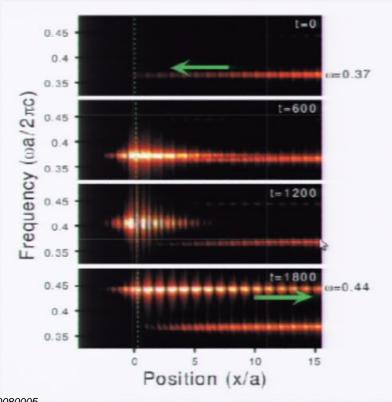


Localization of Light

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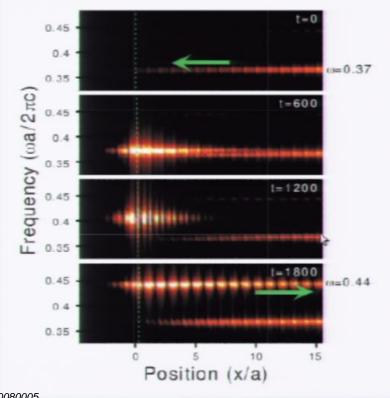


Localization of Light

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In this period, frequency is shifted.

Frequency - Position

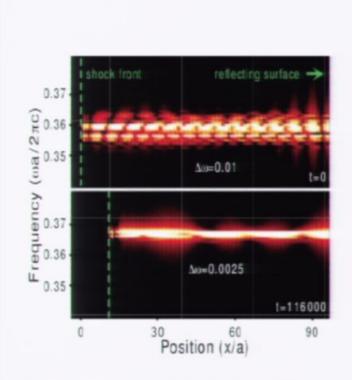


Localization of Light

Light is trapped in a localized state at the shock front in the overlapping bandgap.

In this period, frequency is shifted.

Frequency – Position

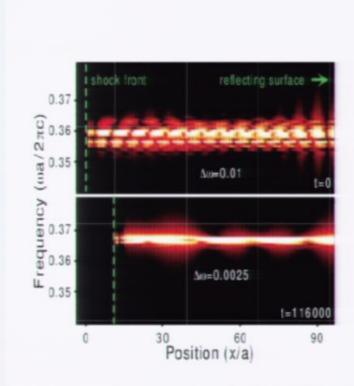


Bandwidth Narrowing

The slower of the shock velocities are, the more the bandwidth is narrowed.

Unlike bandwidth broading, bandwidth narrowing have not been obtained in non-linear systems.

Frequency – Position

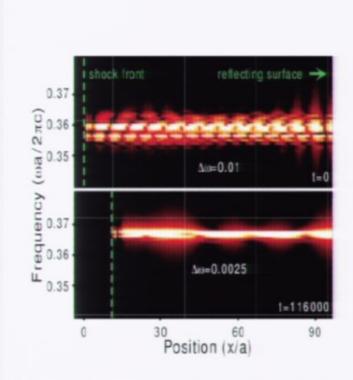


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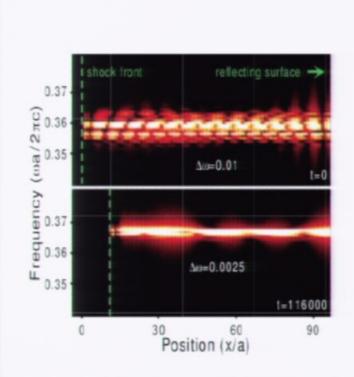


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Frequency – Position

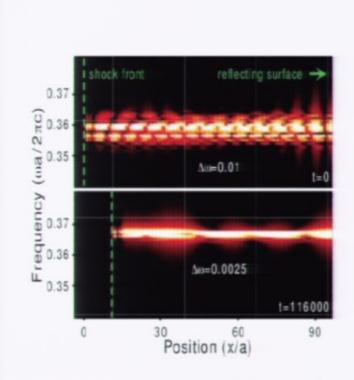


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Frequency – Position

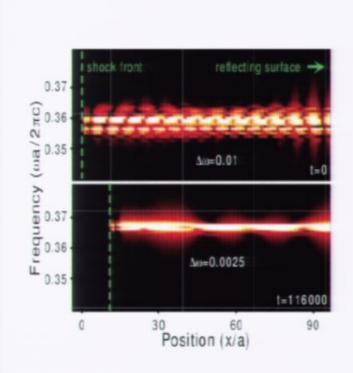


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Frequency - Position

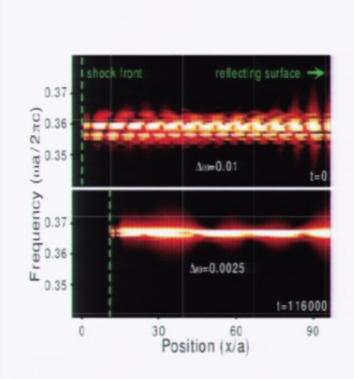


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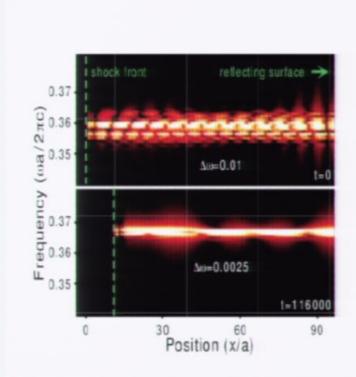


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Frequency – Position

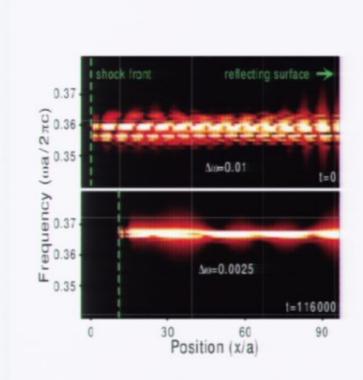


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Frequency - Position

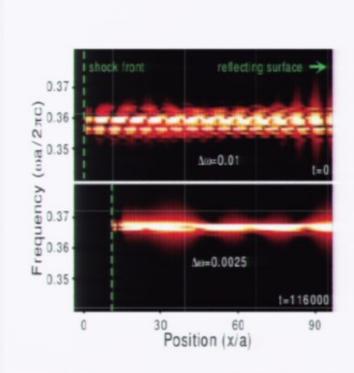


Bandwidth Narrowing

The slower of the shock velocities are, the more the bandwidth is narrowed.

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Frequency - Position

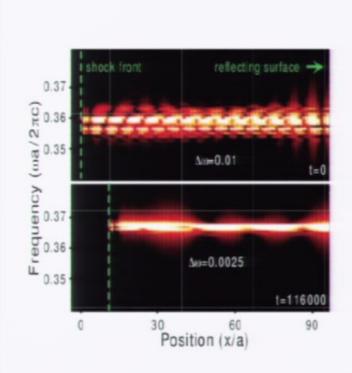


Bandwidth Narrowing

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Frequency - Position

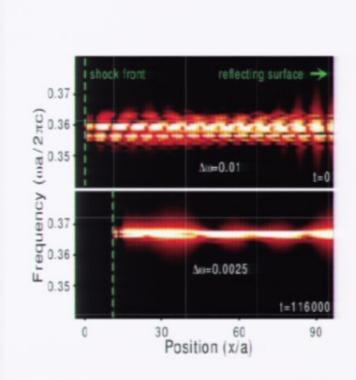


Bandwidth Narrowing

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Frequency – Position

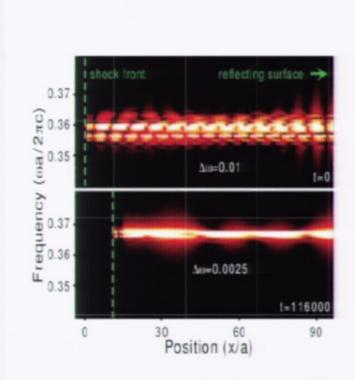


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Frequency – Position

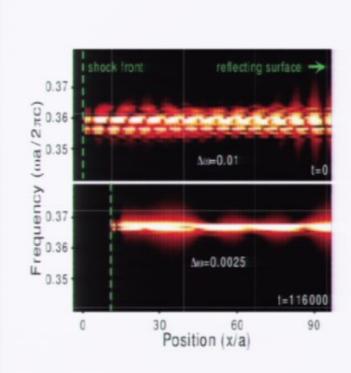


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Frequency - Position

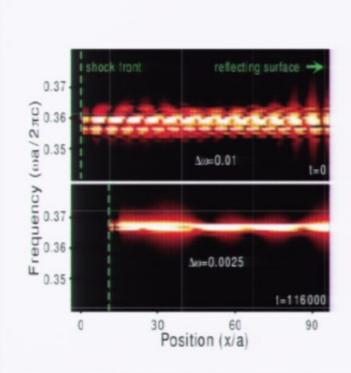


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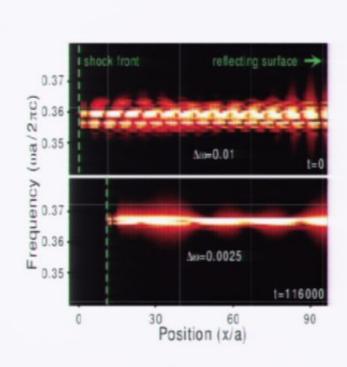


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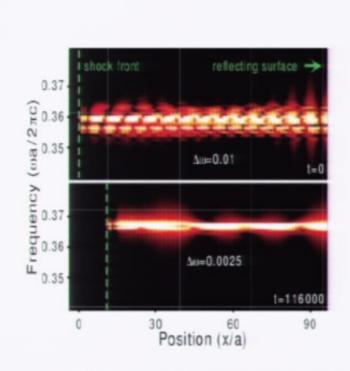


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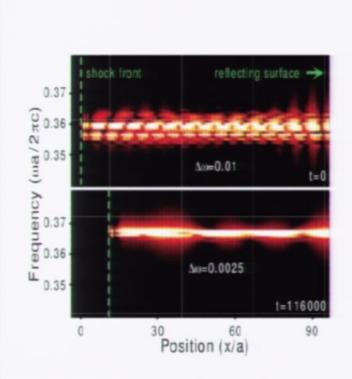


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Frequency - Position

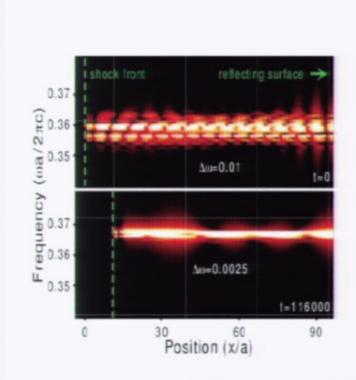


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Frequency – Position

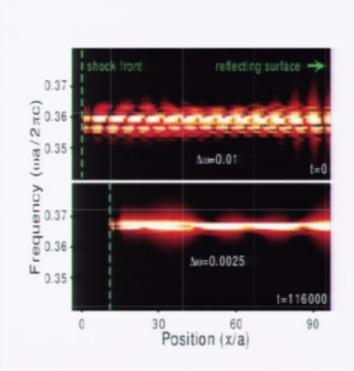


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Frequency – Position

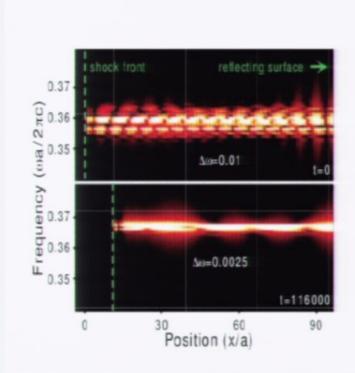


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Frequency - Position

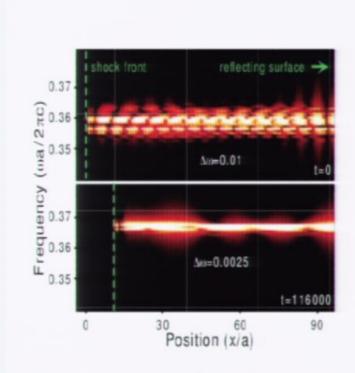


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Frequency – Position

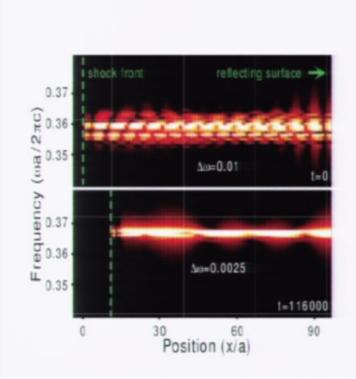


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Frequency - Position

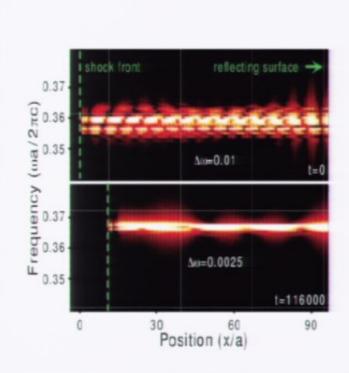


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Frequency - Position

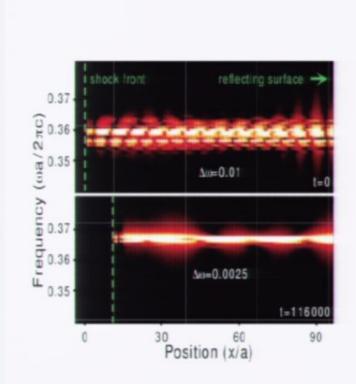


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The slower of the shock velocities are, the more the bandwidth is narrowed.

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Frequency – Position

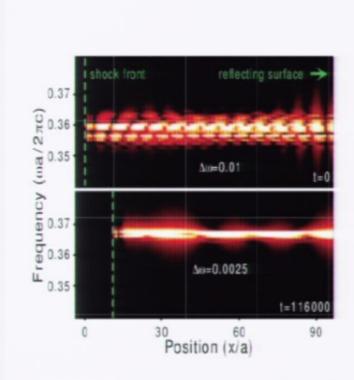


Bandwidth Narrowing

The slower of the shock velocities are, the more the bandwidth is narrowed.

Unlike bandwidth broading, bandwidth narrowing have not been obtained in non-linear systems.

Frequency - Position



Bandwidth Narrowing

The slower of the shock velocities are, the more the bandwidth is narrowed.

Unlike bandwidth broading, bandwidth narrowing have not been obtained in non-linear systems.

Colorful Nature Creative Human Reference Acknowledgement

Concept of Photonic Crystal Design Your Photonic Crystal Unexpected New Phenomena

Possible Properties

No photon absorbed or re-emitted

Colorful Nature Creative Human Reference Acknowledgement

Concept of Photonic Crystal Design Your Photonic Crystal Unexpected New Phenomena

Possible Properties

No photon absorbed or re-emitted

No measurement on the photons

Pirsa: 10080005 Page 287/896

Possible Properties

No photon absorbed or re-emitted

No measurement on the photons

The state of the photon may be changed slightly, preserving a quantum entanglement with another photon.

Pirsa: 10080005 Page 288/896

No photon absorbed or re-emitted

No measurement on the photons

The state of the photon may be changed slightly, preserving a quantum entanglement with another photon.

Pirsa: 10080005 Page 289/896

No photon absorbed or re-emitted

No measurement on the photons

The state of the photon may be changed slightly, preserving a quantum entanglement with another photon.

Pirsa: 10080005 Page 290/896

No photon absorbed or re-emitted

No measurement on the photons

The state of the photon may be changed slightly, preserving a quantum entanglement with another photon.

Pirsa: 10080005 Page 291/896

No photon absorbed or re-emitted

No measurement on the photons

The state of the photon may be changed slightly, preserving a quantum entanglement with another photon.

Pirsa: 10080005 Page 292/896

No photon absorbed or re-emitted

No measurement on the photons

The state of the photon may be changed slightly, preserving a quantum entanglement with another photon.

Pirsa: 10080005

No photon absorbed or re-emitted

No measurement on the photons

The state of the photon may be changed slightly, preserving a quantum entanglement with another photon.

Pirsa: 10080005 Page 294/896

No photon absorbed or re-emitted

No measurement on the photons

The state of the photon may be changed slightly, preserving a quantum entanglement with another photon.

Pirsa: 10080005 Page 295/896

Colorful Nature Creative Human Reference Acknowledgement

Reference

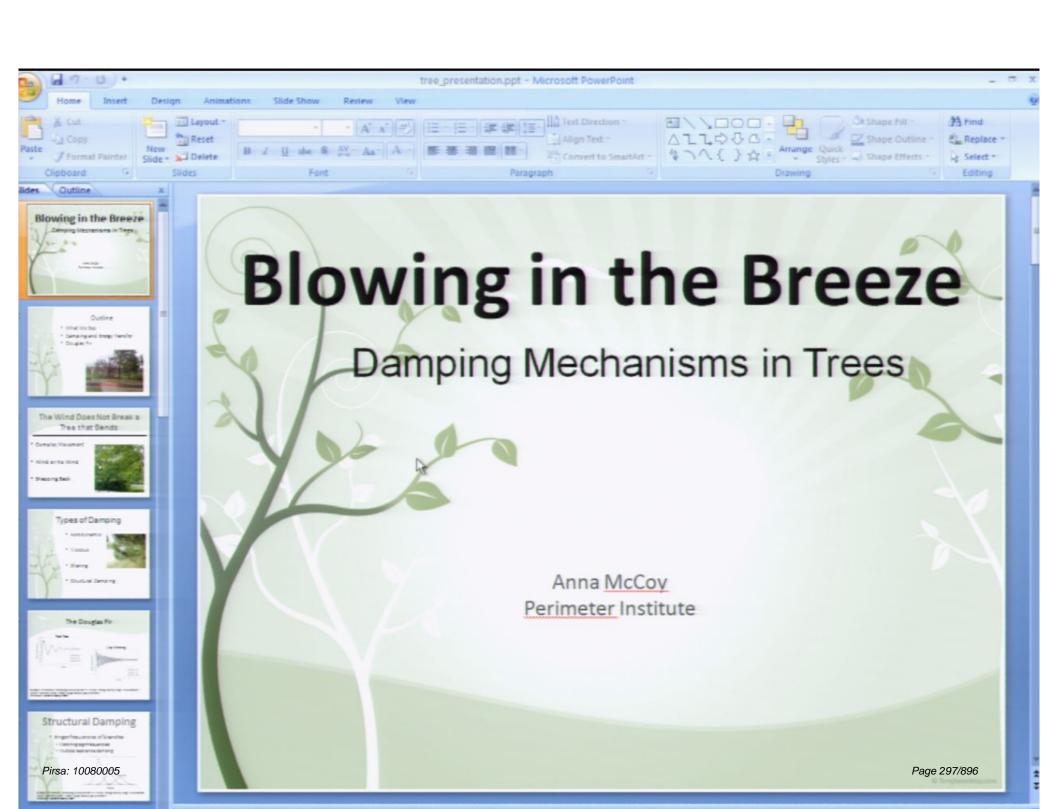
[1]http://en.wikipedia.org/wiki/Photonic_crystal

[2]http://en.wikipedia.org/wiki/Opal

[3] Solid State Communications, Vol.102, No.2-3, pp.165-173, 1997

[4] The color of shock waves in photonic crystals

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Outline

- What We See
- Damping and Energy Transfer
- Douglas Fir



Outline

- What We See
- Damping and Energy Transfer
- Douglas Fir



The Wind Does Not Break a Tree that Bends

Complex Movement

Wind or No Wind

Snapping Back



Types of Damping

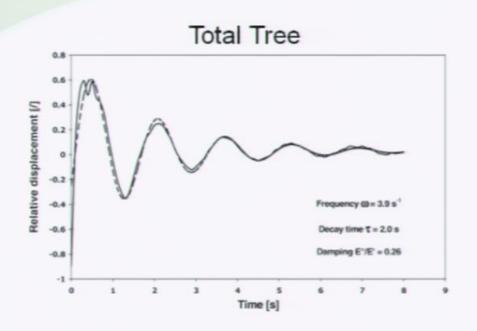
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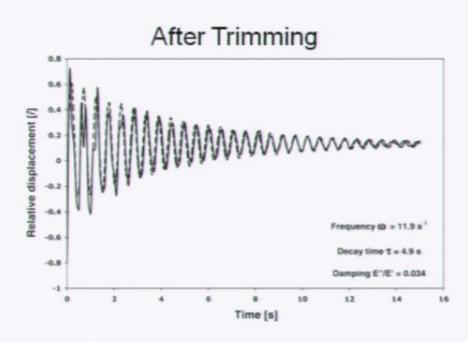
Viscous

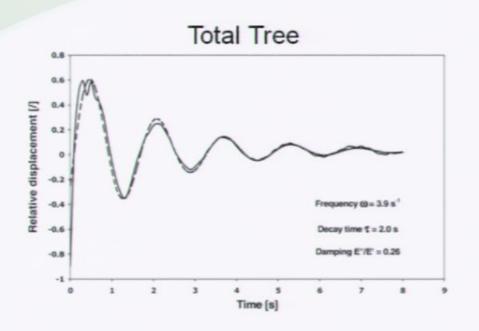
Sharing

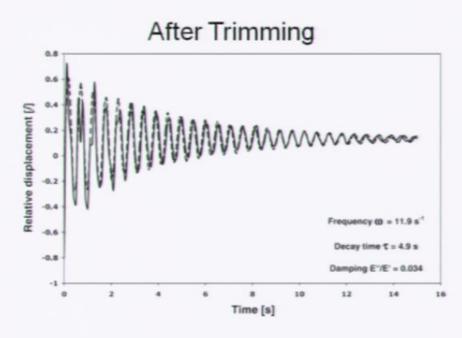


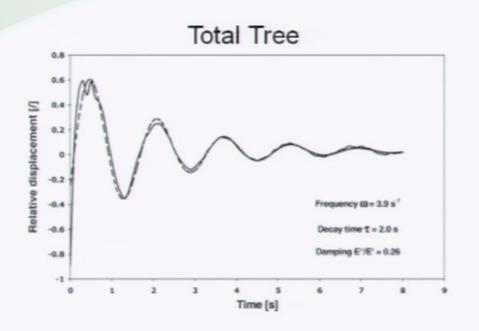
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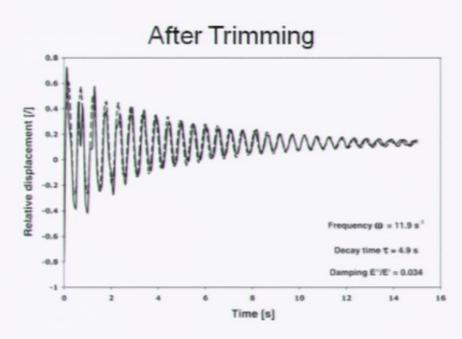


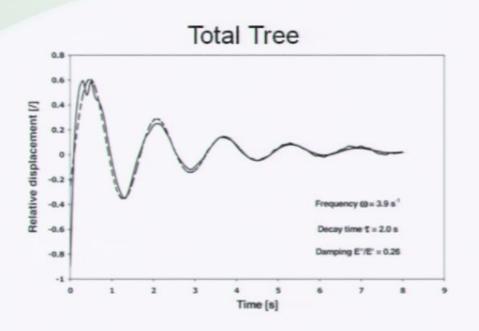


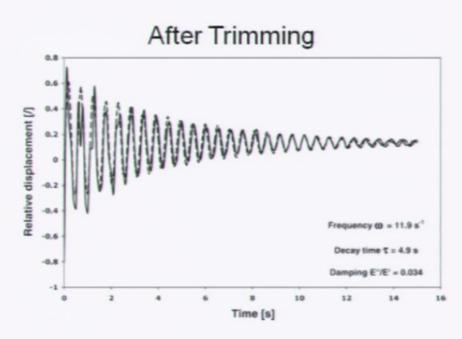


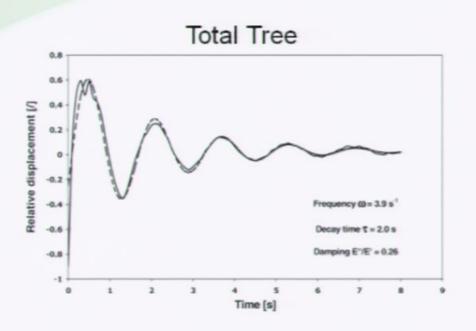


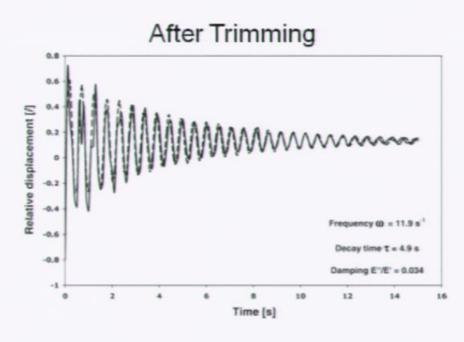


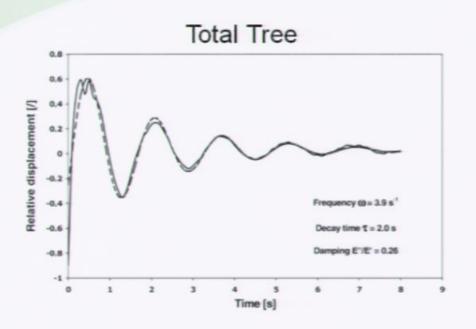


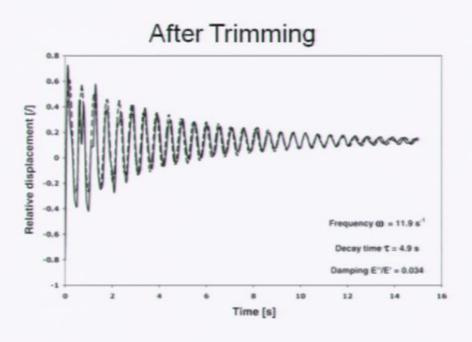


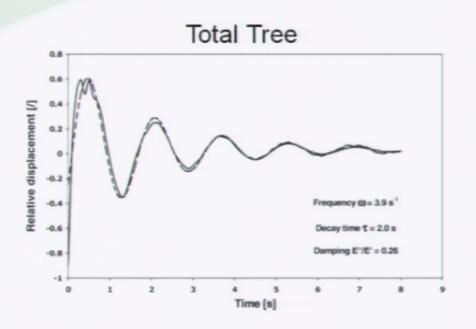


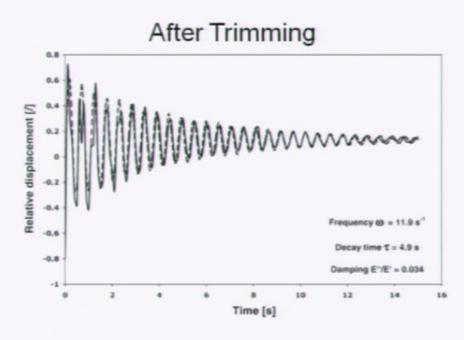


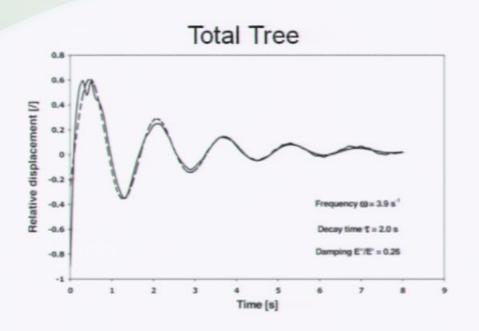


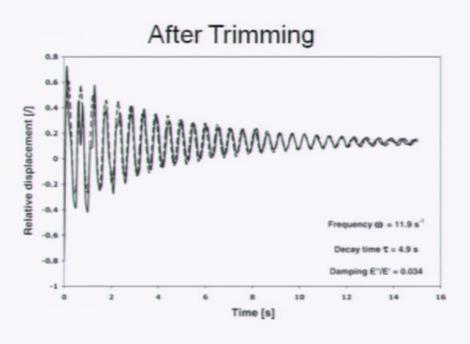


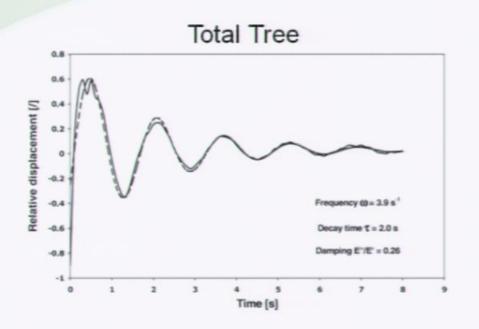


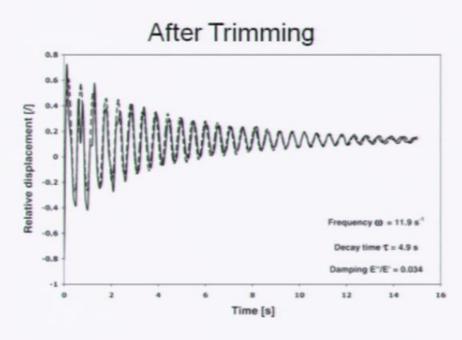


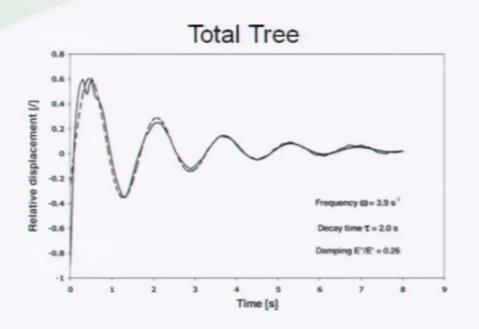


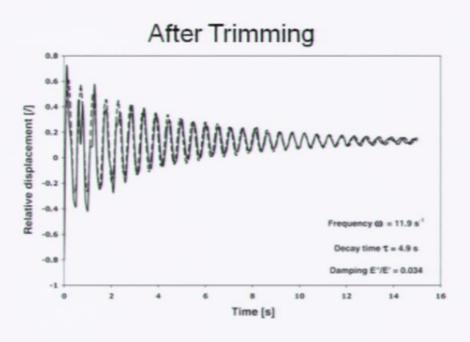


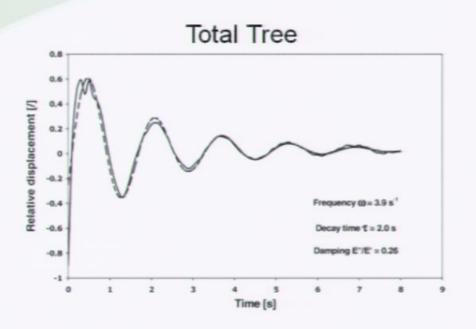


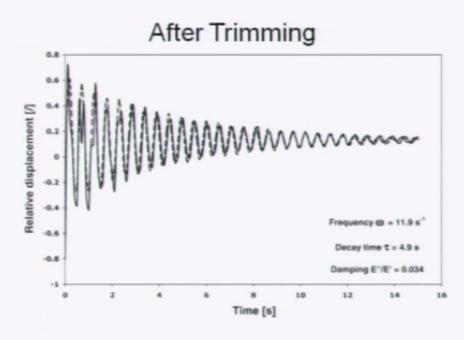


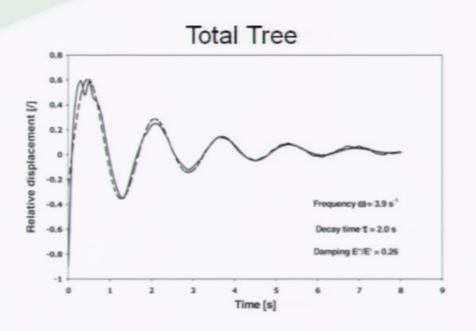


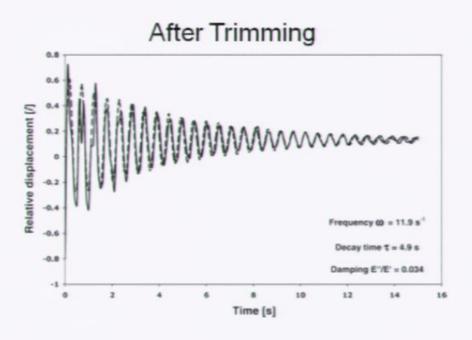


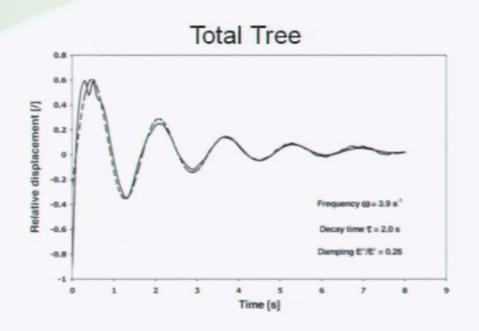


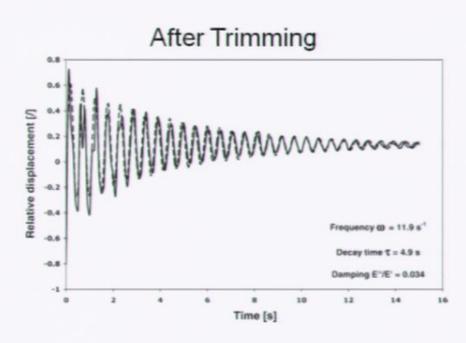


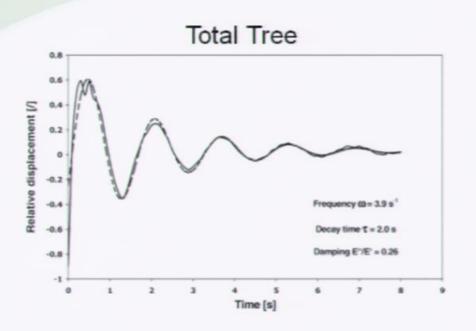


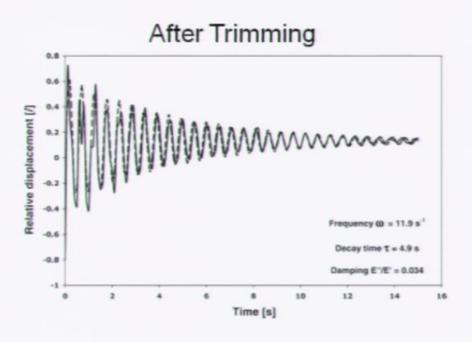


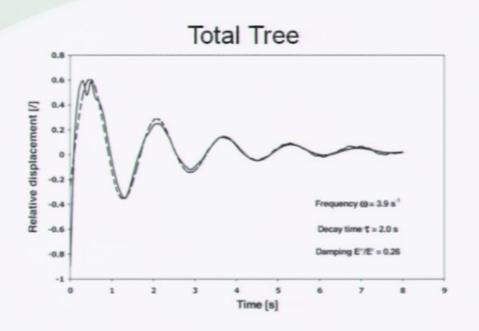


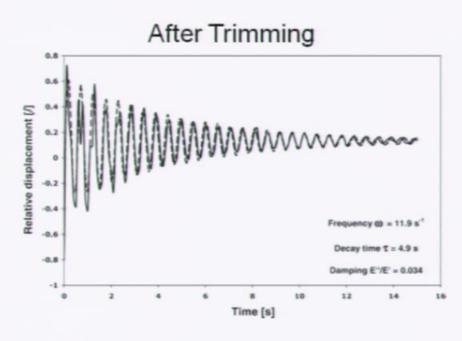


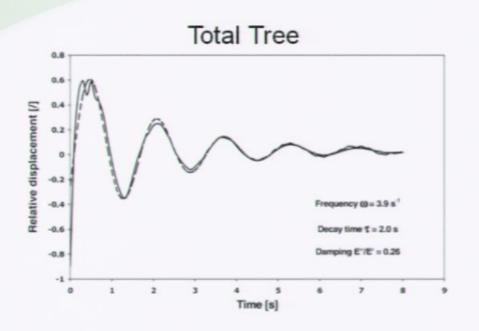


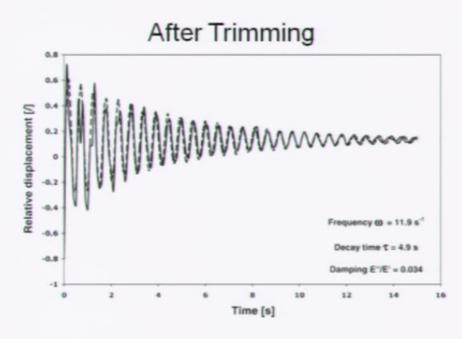


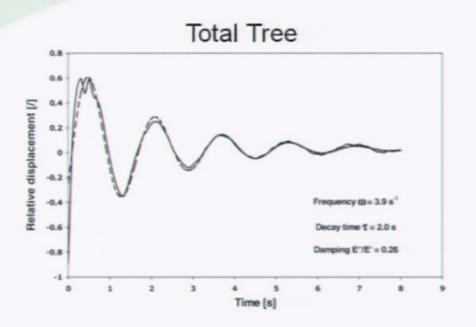


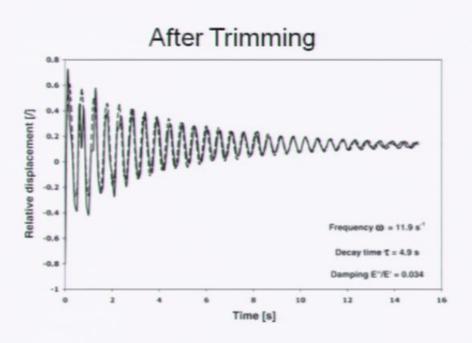


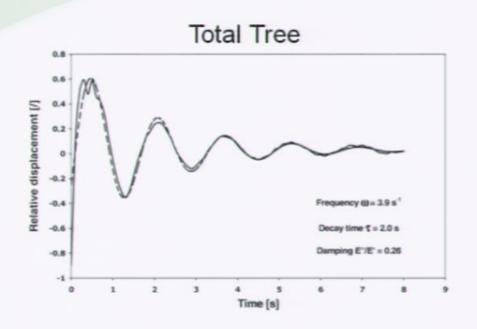


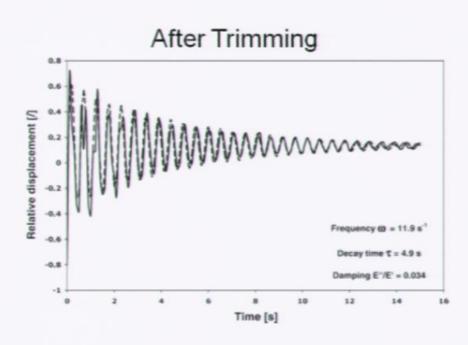


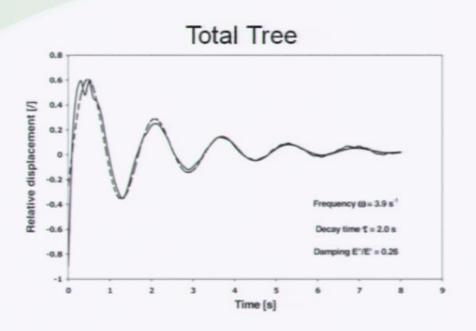


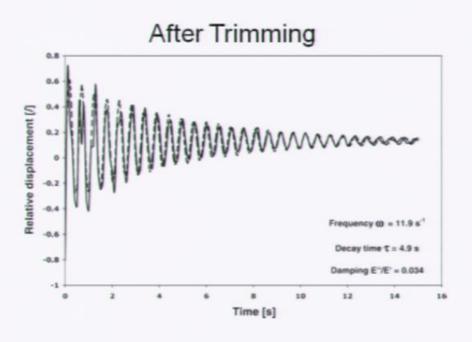


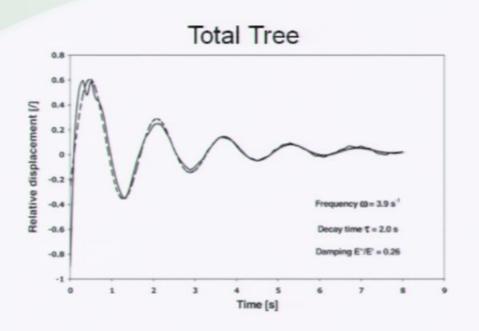


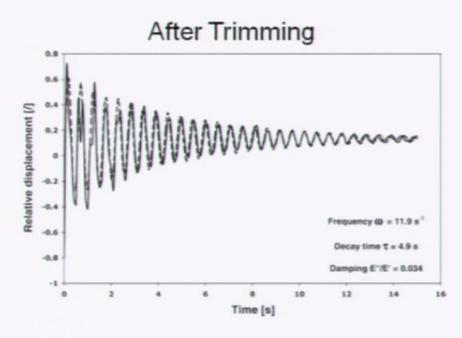


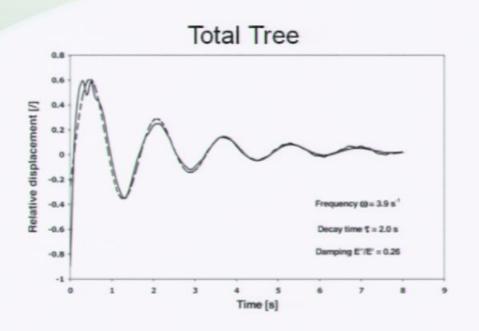


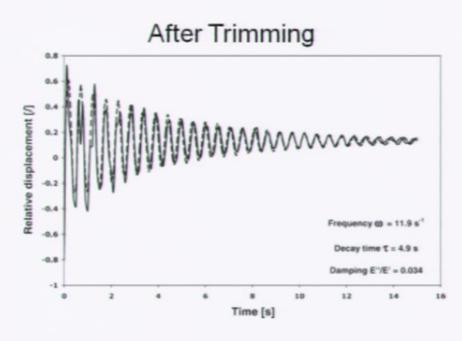


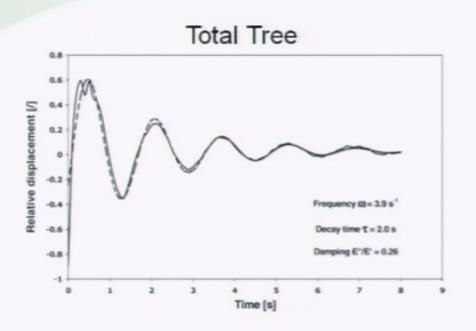


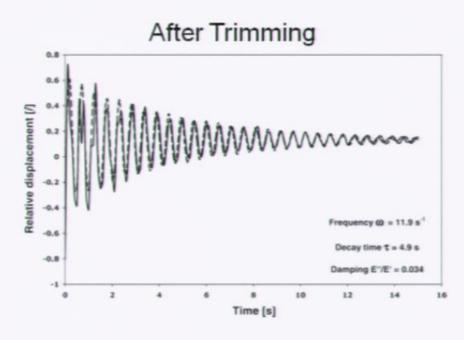


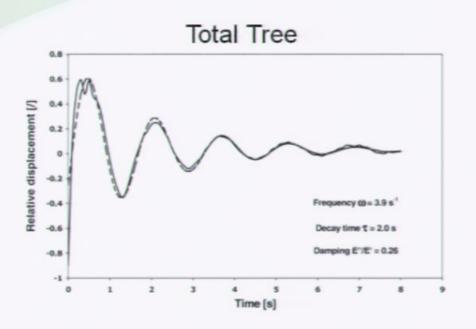


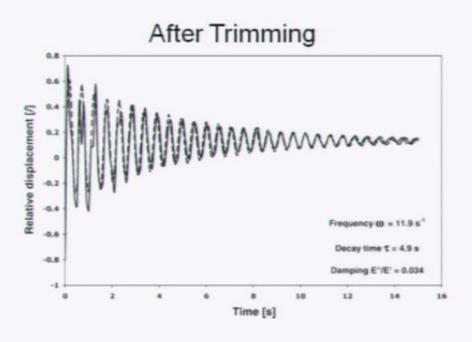


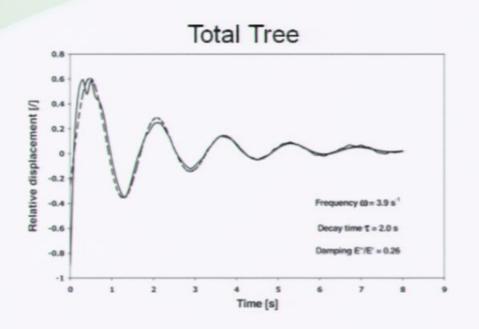


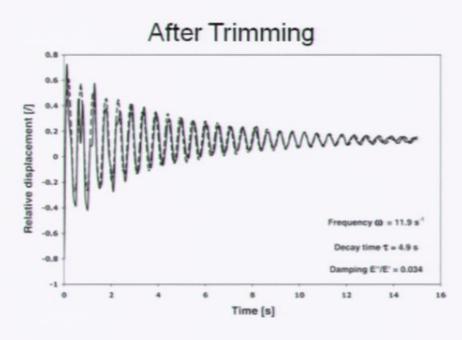


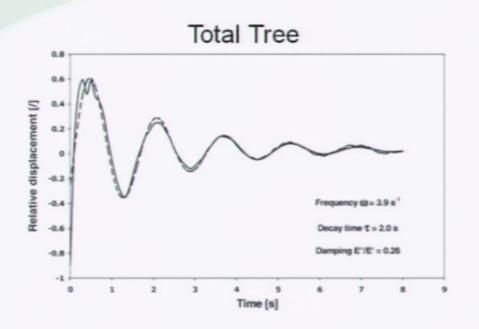


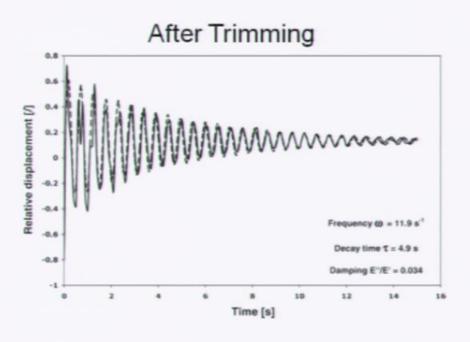


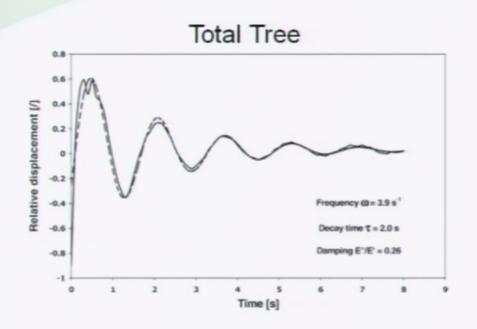


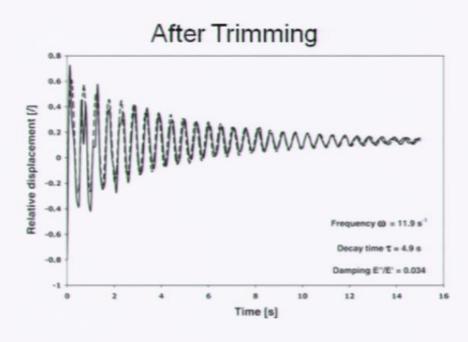


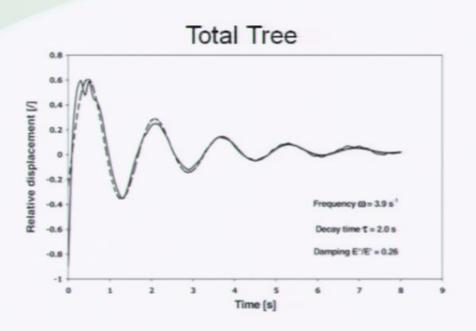


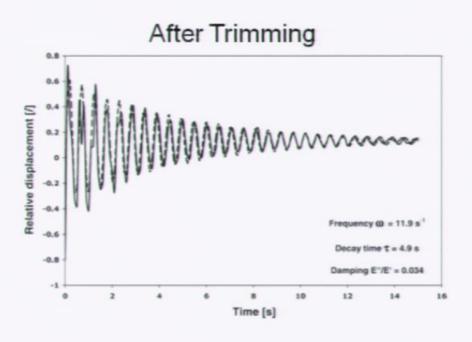


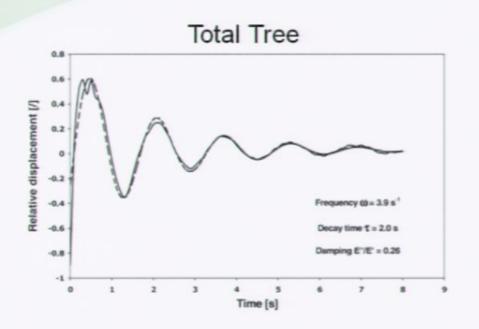


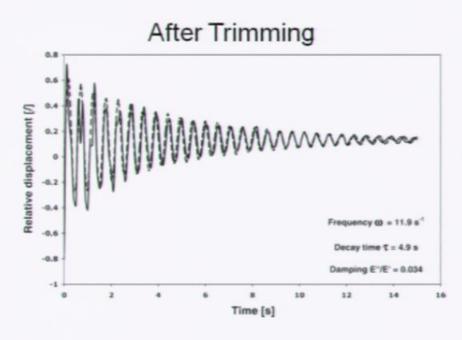


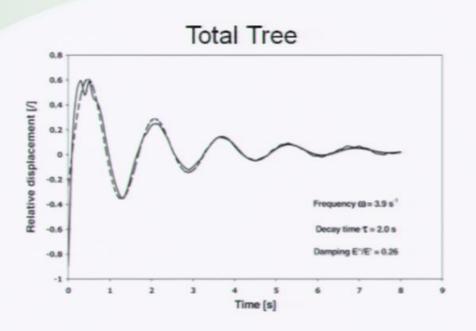


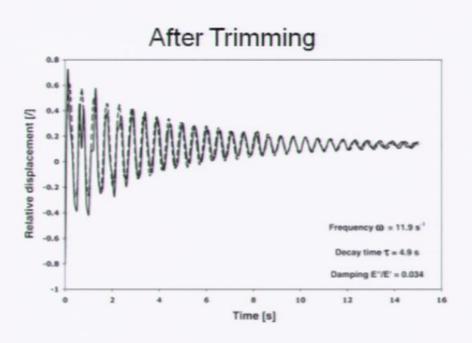


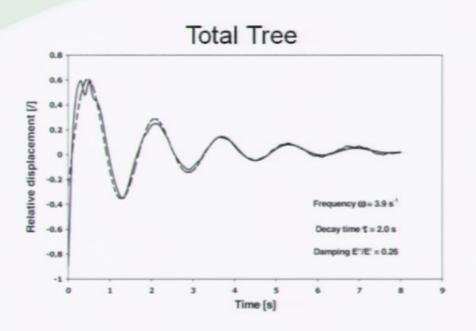


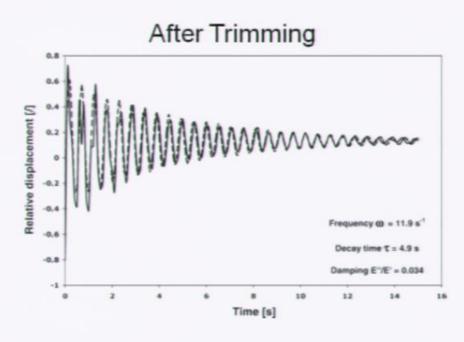


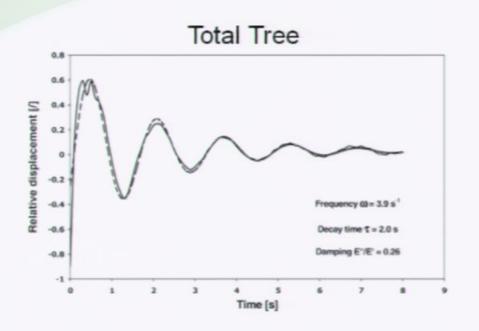


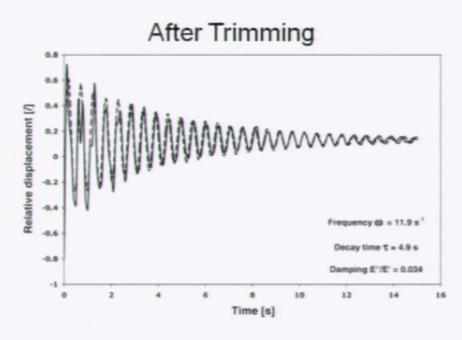


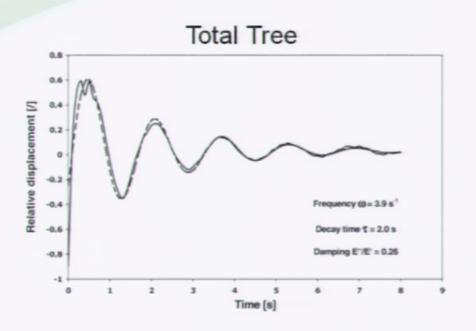


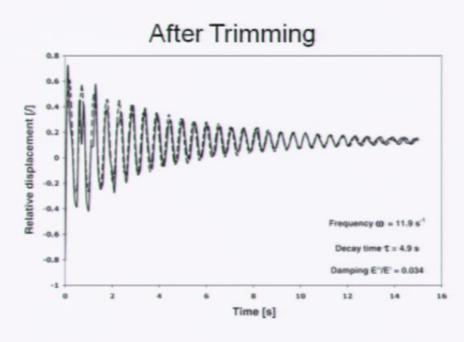


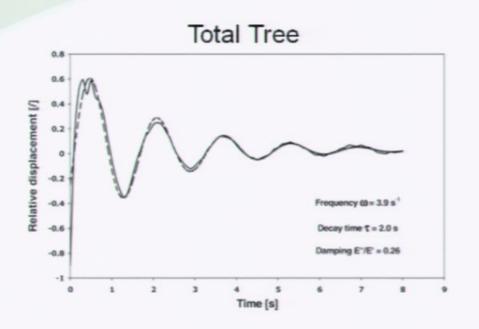


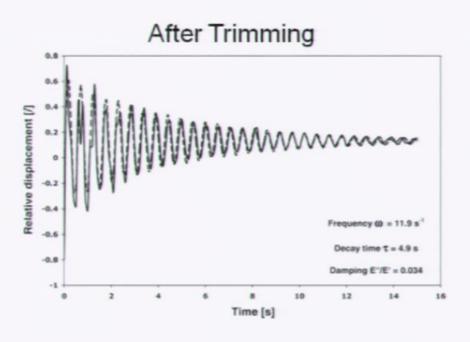


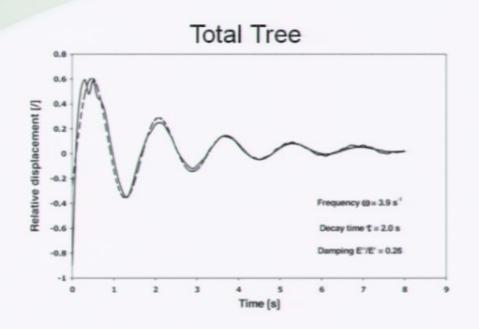


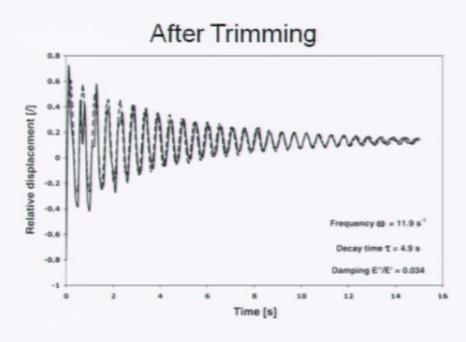


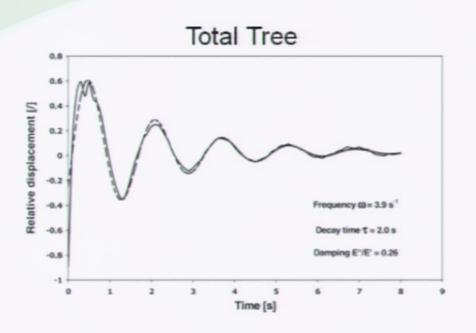


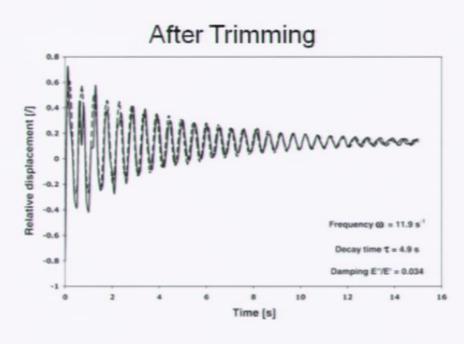


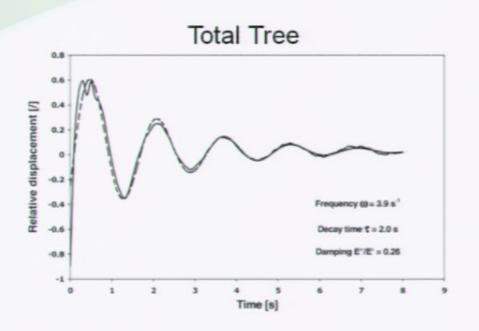


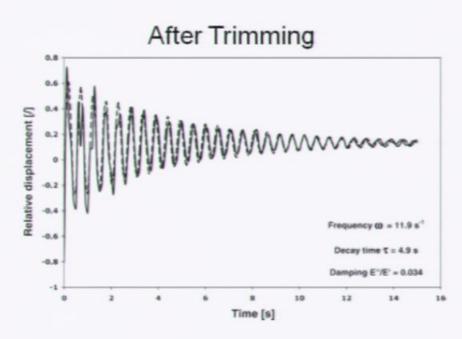


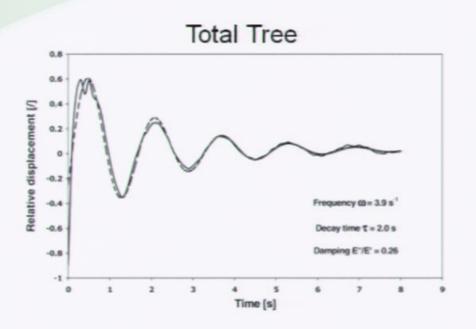


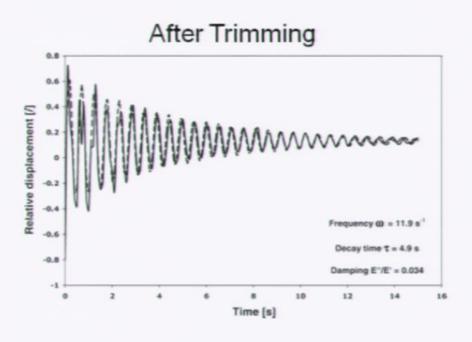


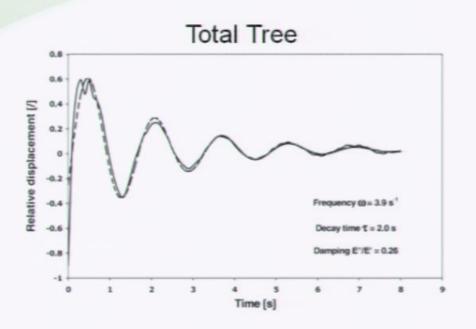


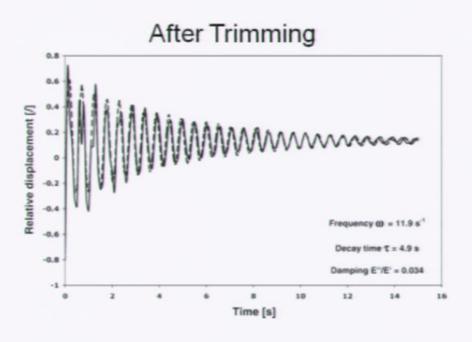


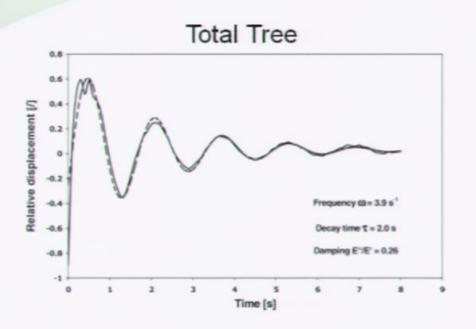


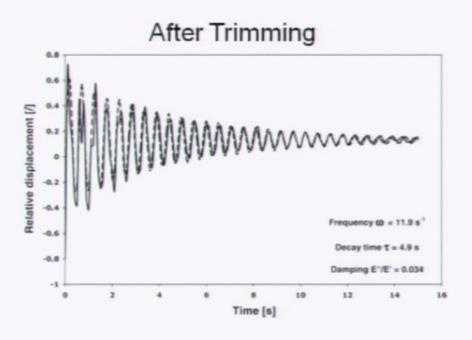


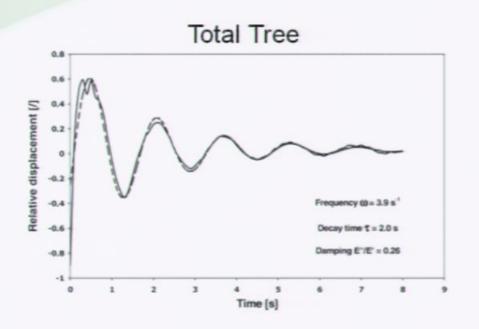


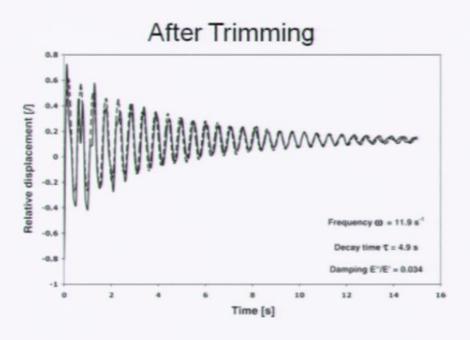


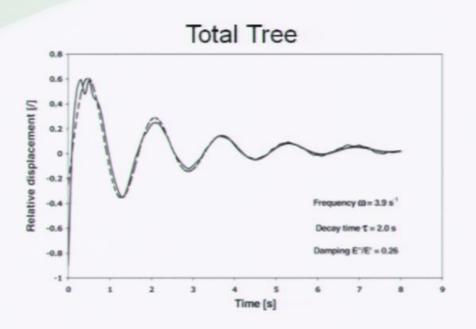


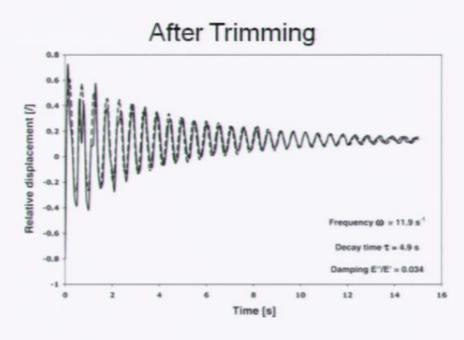


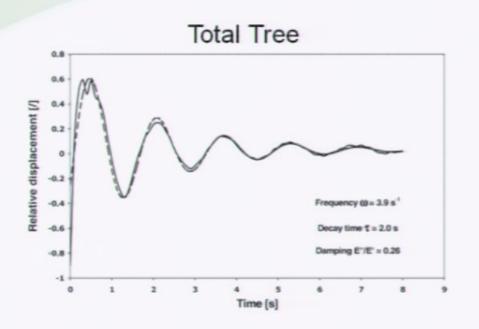


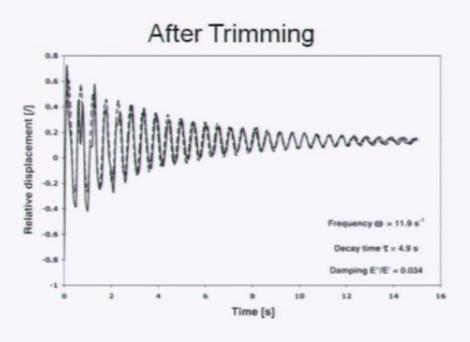


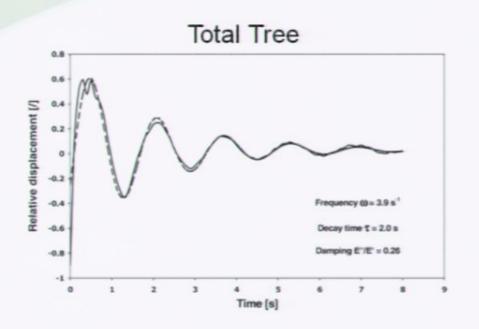


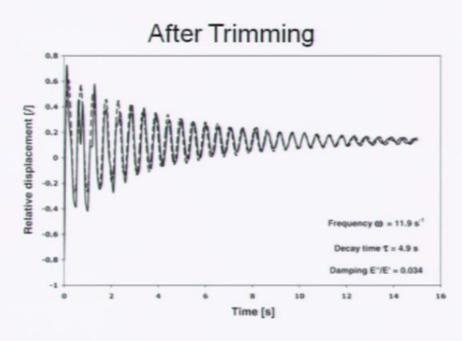


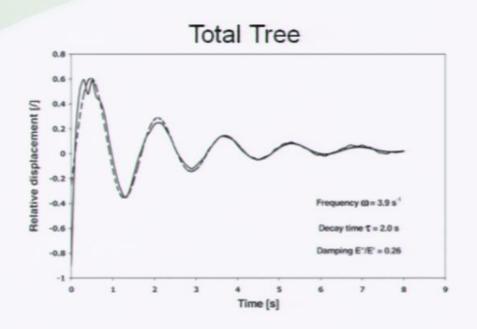


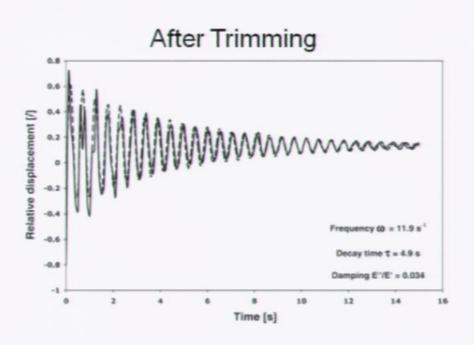


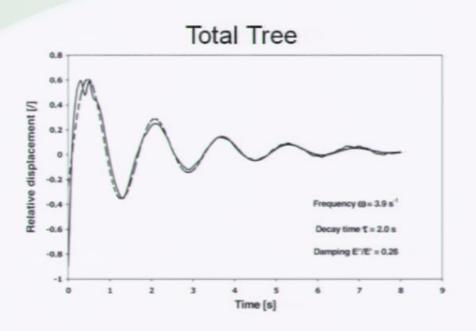


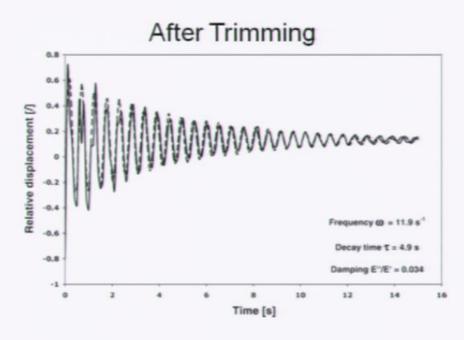


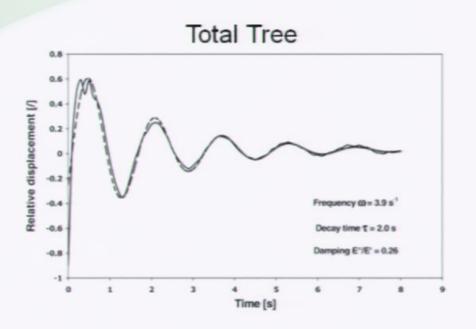


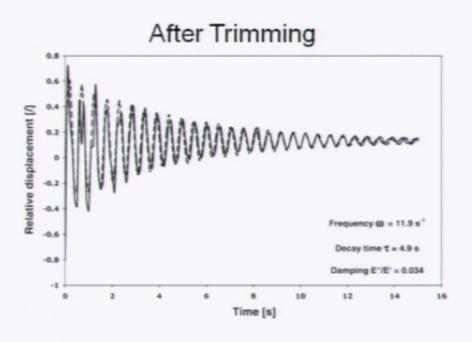


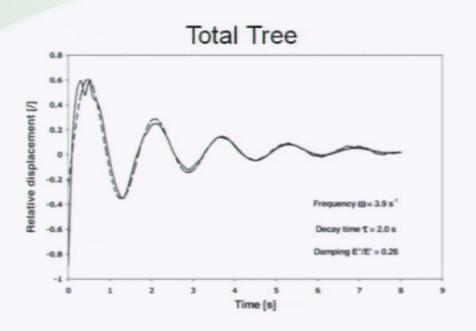


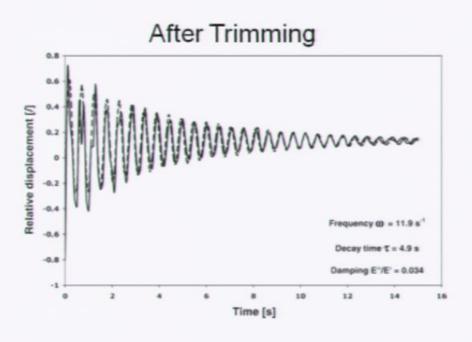


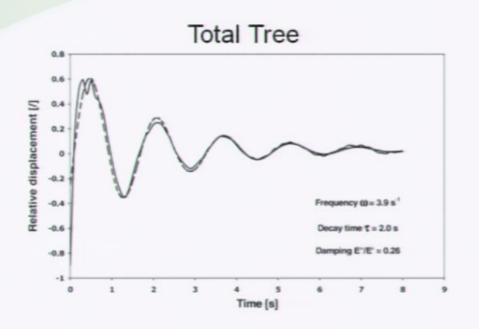


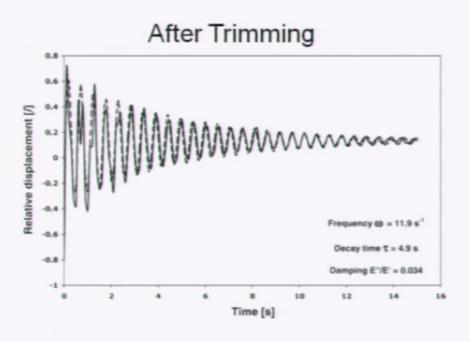


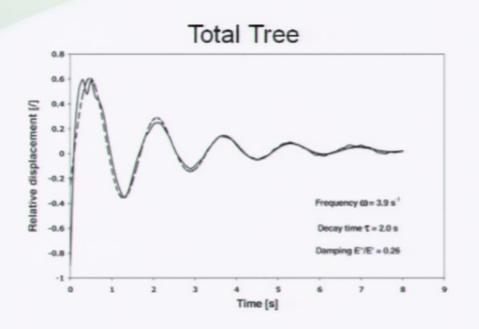


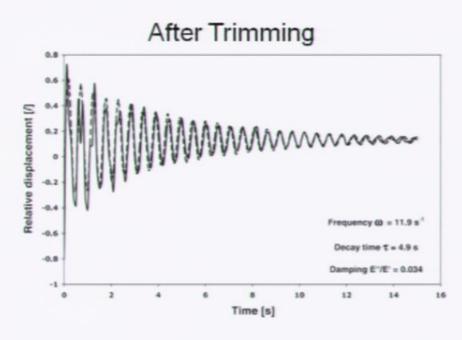


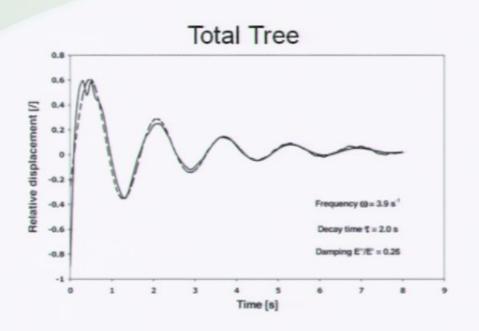


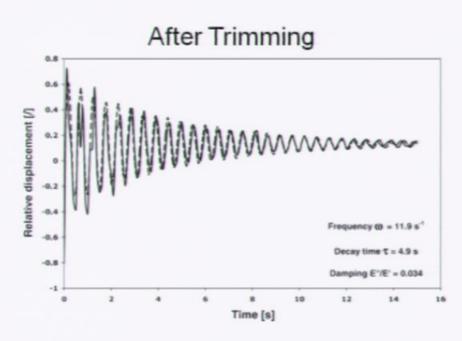


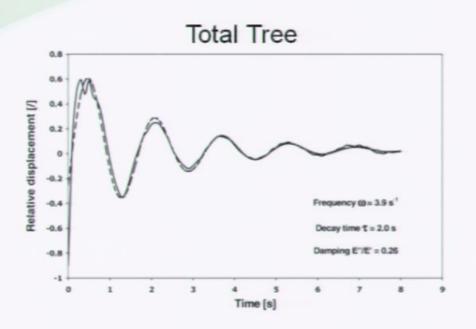


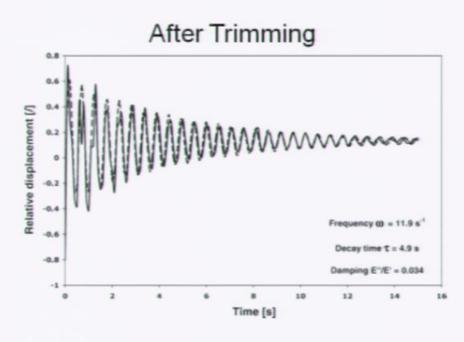


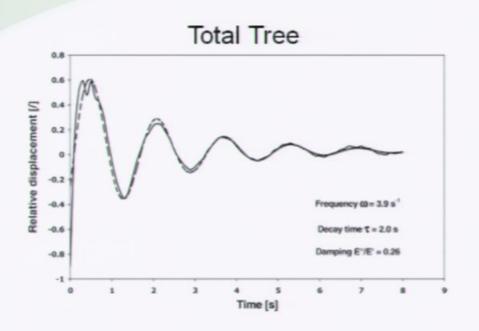


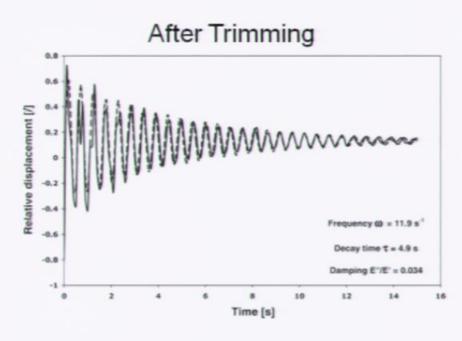


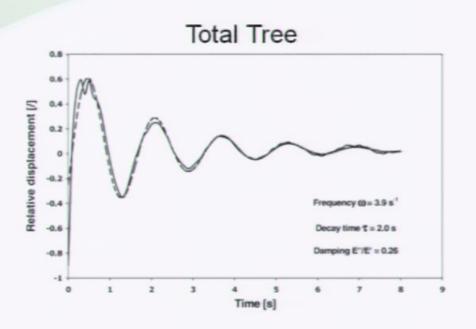


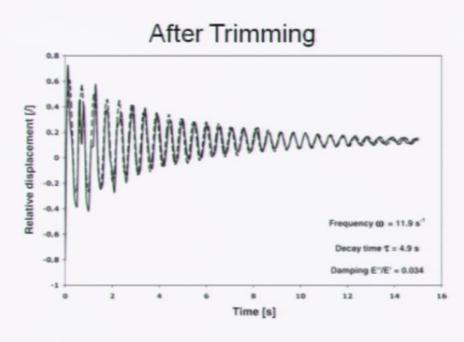


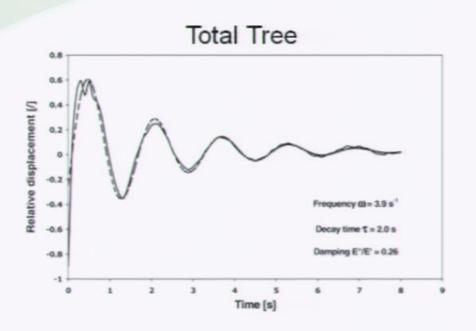


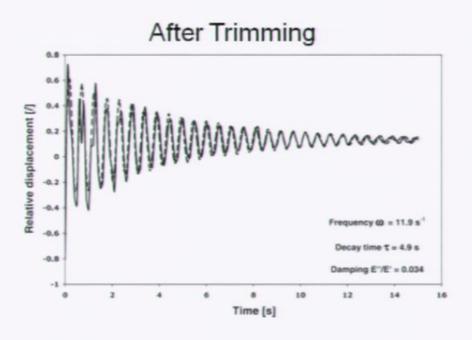


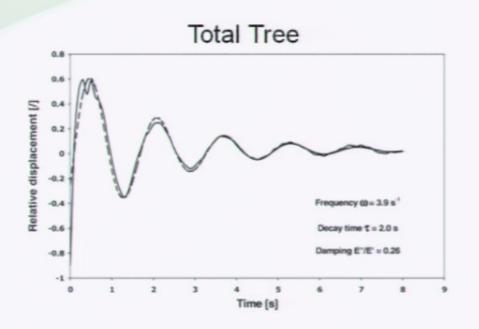


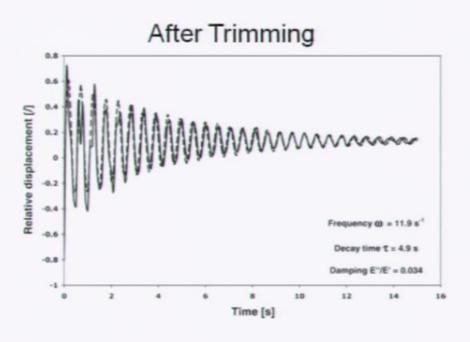


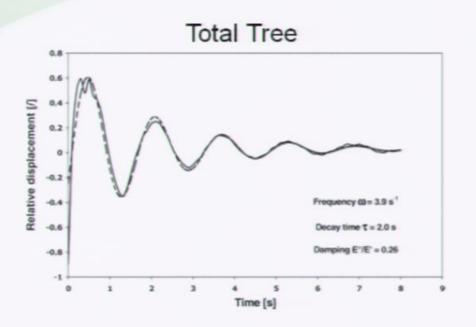


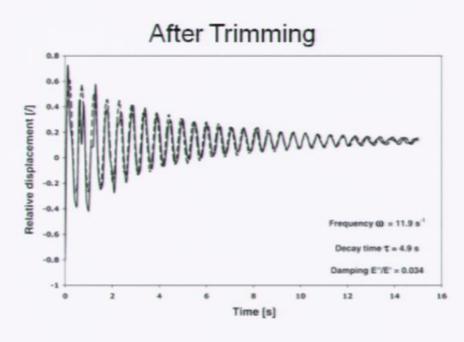


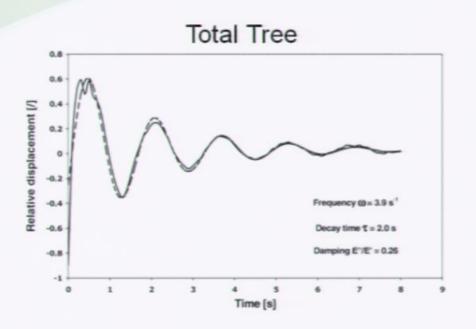


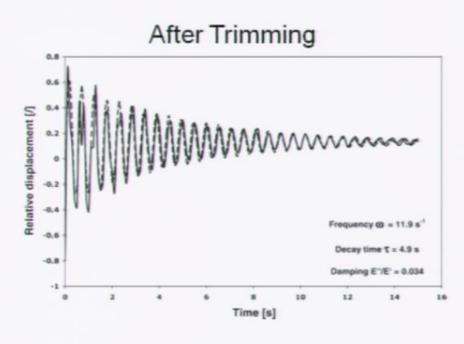


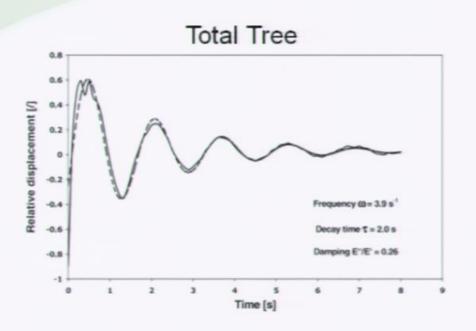


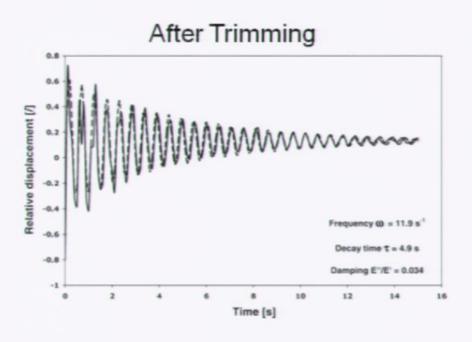


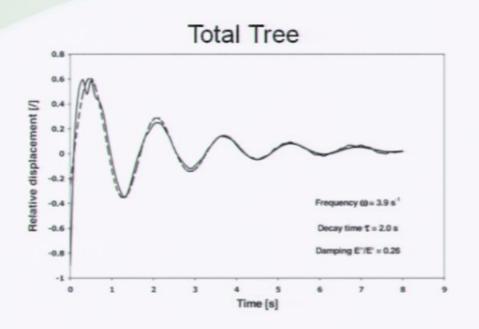


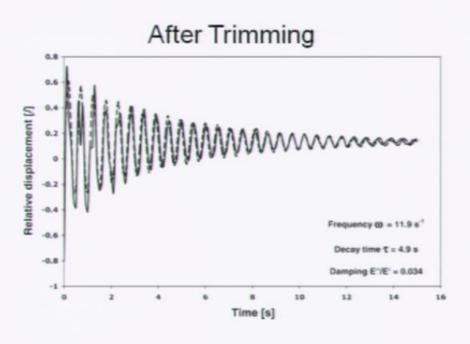




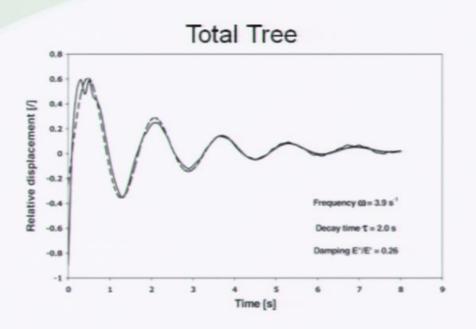


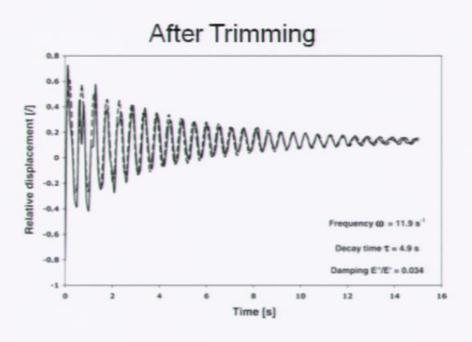




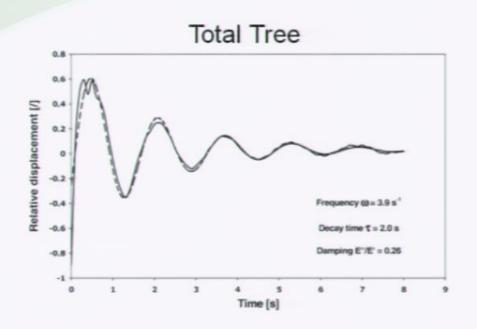


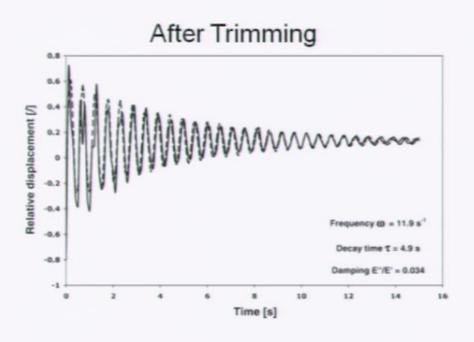
The Douglas Fir



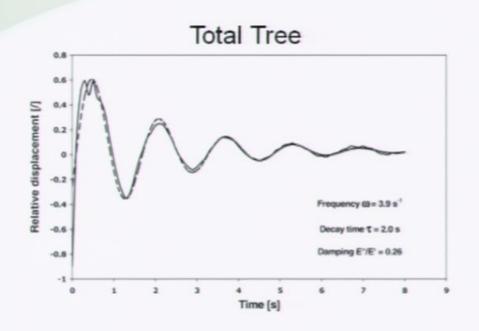


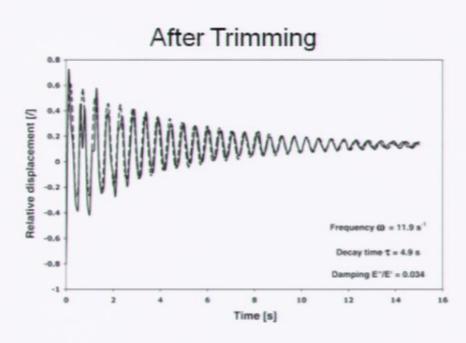
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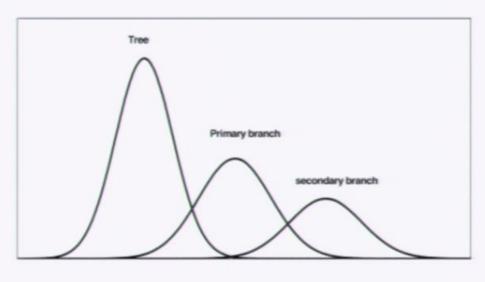


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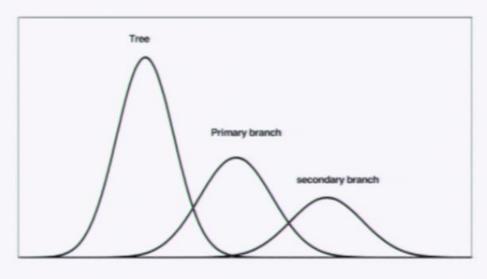


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 - Matching eignfrequencies
 - Multiple resonance damping



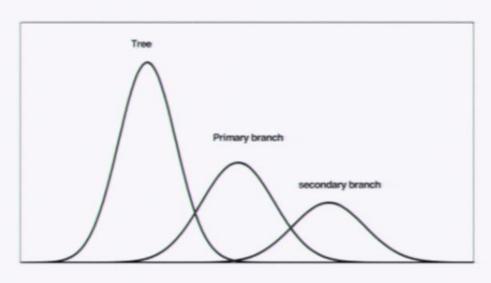
Frequency

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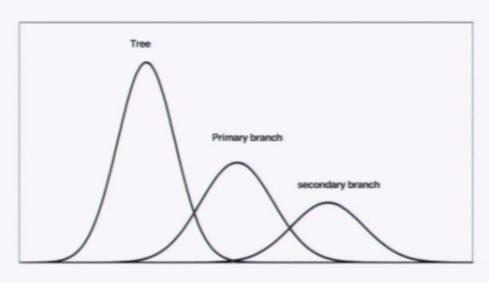
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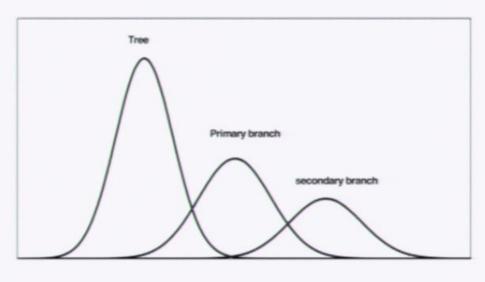
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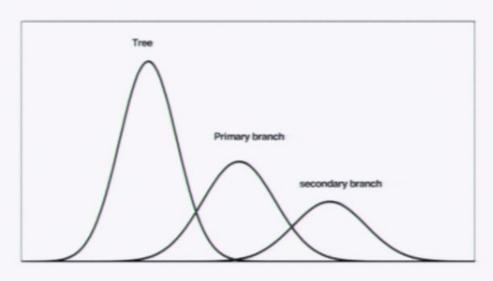
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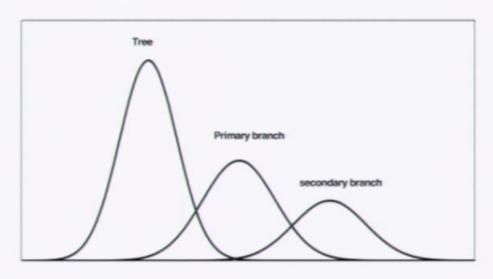
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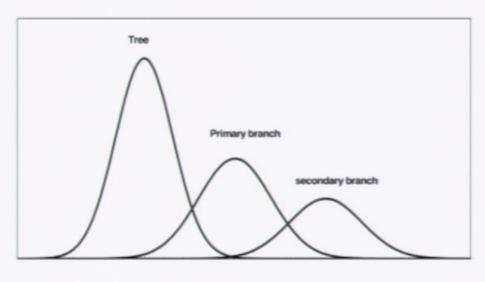
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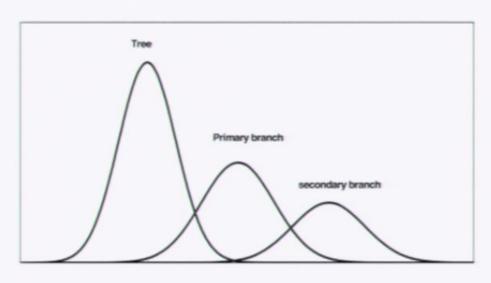
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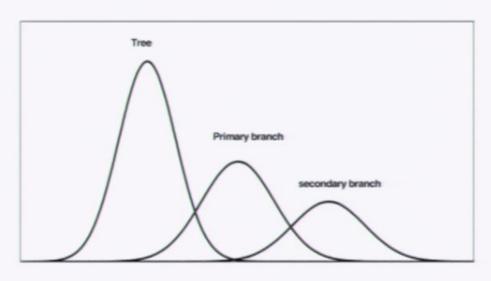
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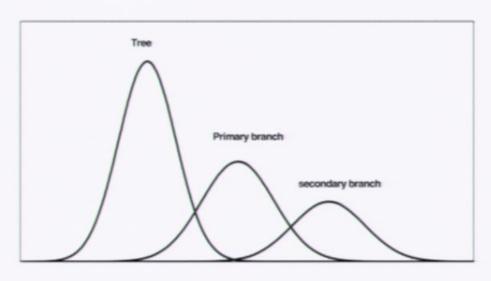
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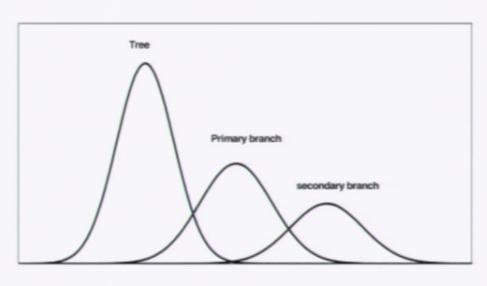
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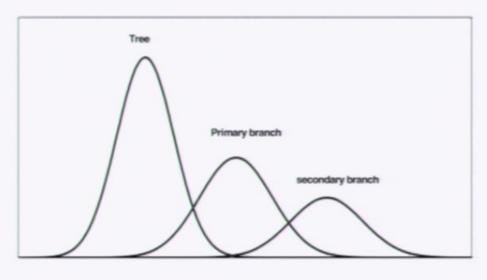
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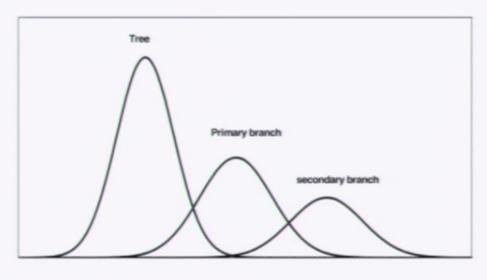
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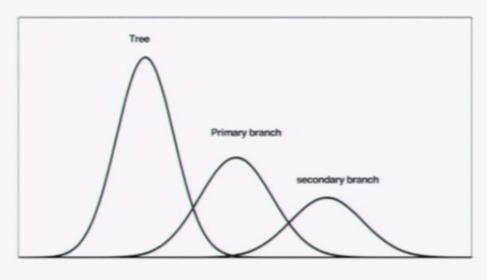
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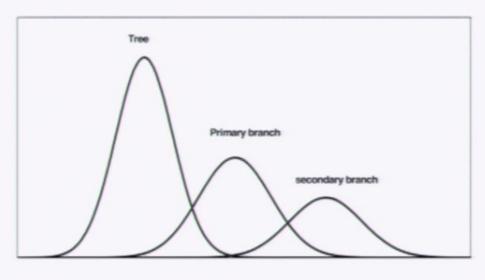
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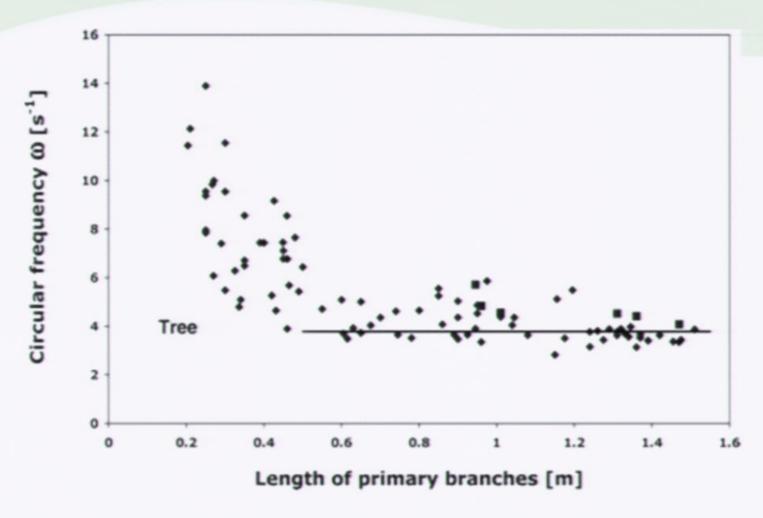
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Frequency

Branch Statistics



Multiple resonance damping or how do trees escape dangerously large oscillations

Concluding Remarks

Optimizes damping

Reduces danger

Further experiments

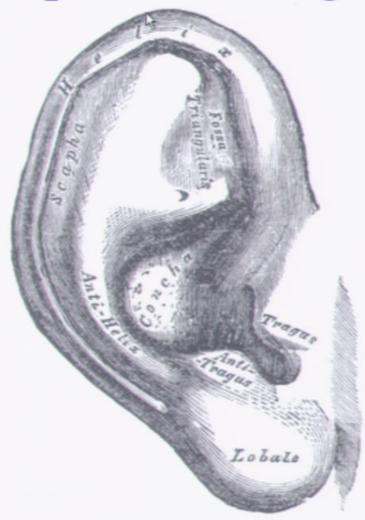
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Spatial Hearing and Sound Localization



Lauren Greenspan Perimeter Institute

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- Hearing in 3-D
- Filtering out the "noise"
- Ears favor frequencies of human speech
 - Psychophysics scientific study of perceptual system

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- Sound Localization Cues
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 - Interaural Level Differences (ILD)
 - Wave interference
 "Spatial Hearing and Understanding Speech in Complex Environments" T. Neher, T. Behrens, D.L. Beck
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 - Interaural Time Difference (ITD)
 - Interaural Level Differences (ILD)
 - Wave interference
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 - Spectral filtering of the head and torso
- The Pinna

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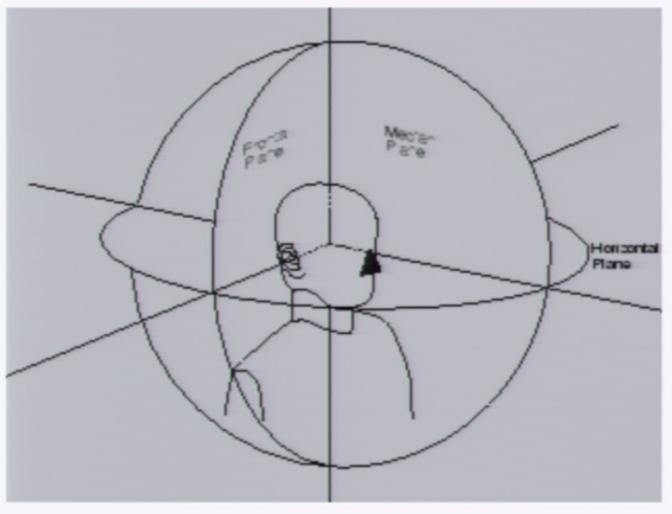
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Coordinate System



Pirsa: 10080005

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- Phase difference between the ears causes time delay
- Helps localize sound's origin
- Most useful for frequencies below 1500 Hz

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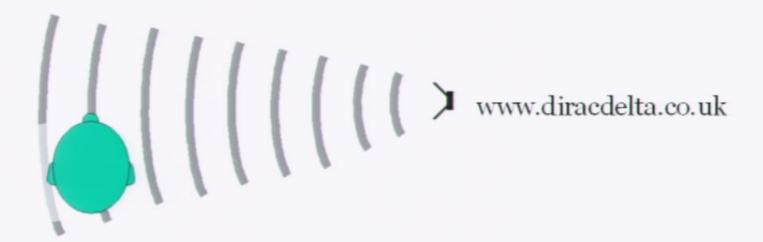
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Interaural Level Difference (ILD)

- Negligible for frequencies below 1000 Hz
- Sound intensity "shadowed" by head



- Proposed by Lord Rayleigh in 1907
- Combines ITD's and ILD's to explain full spectrum sound localization for pure tones
- Cone of confusion
 - Resolved by head movements for pure tones

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- Take into account spectral filtering of torso, head, pinna, etc.

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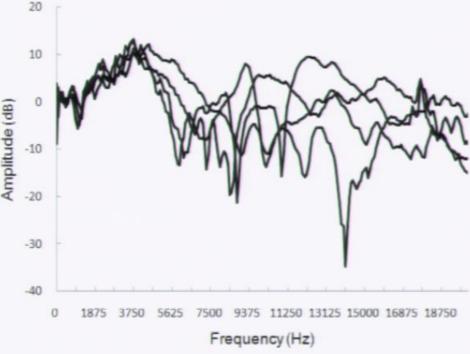
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Not analytically described

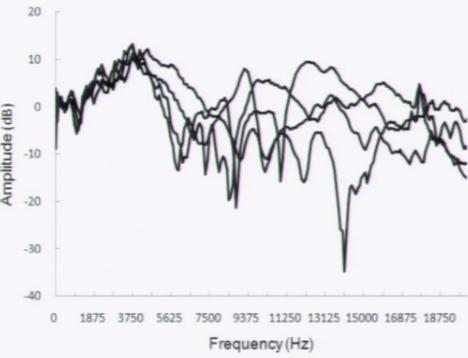
 Acts as a funnel a low frequencies



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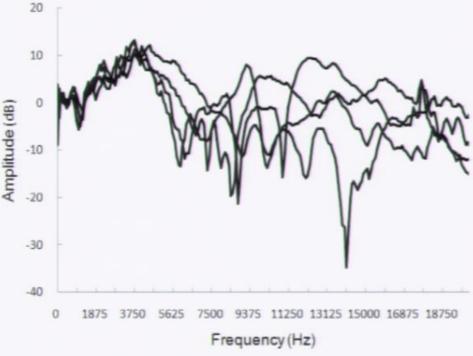
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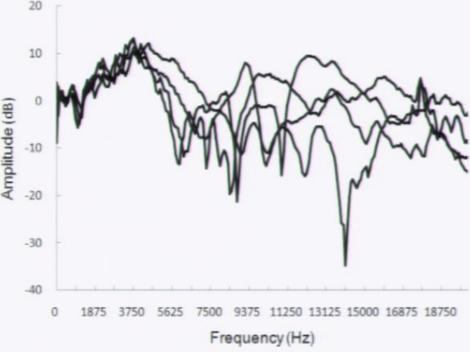
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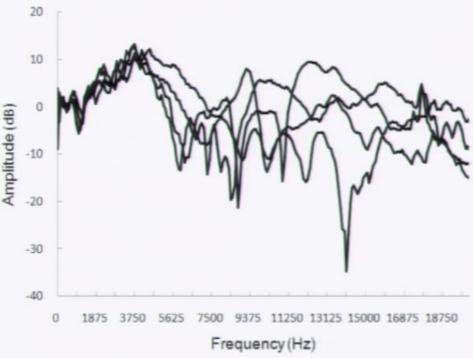
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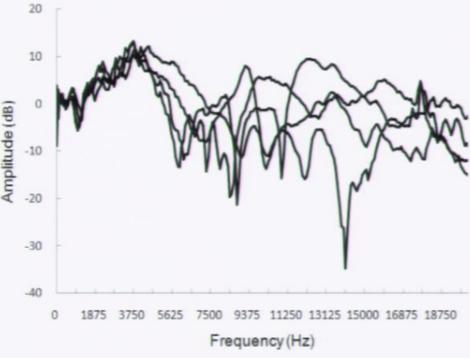
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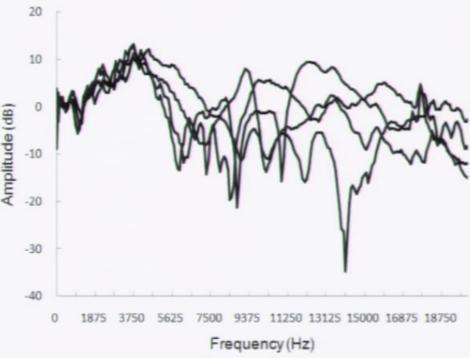
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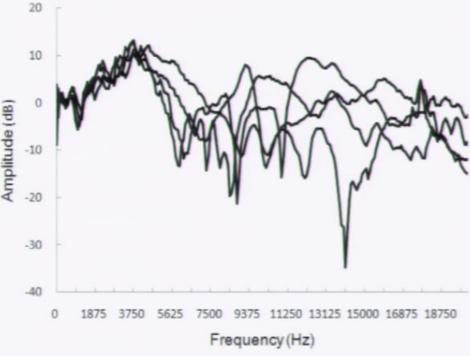
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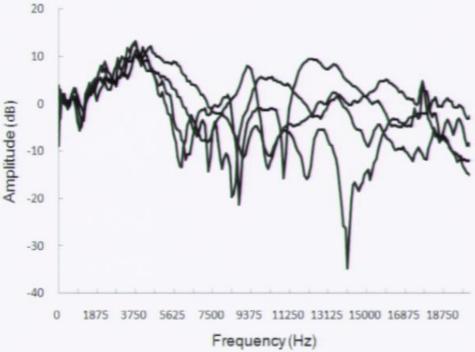
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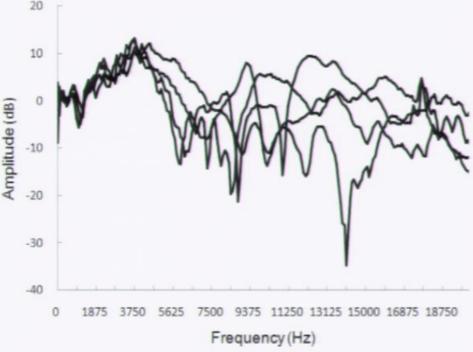
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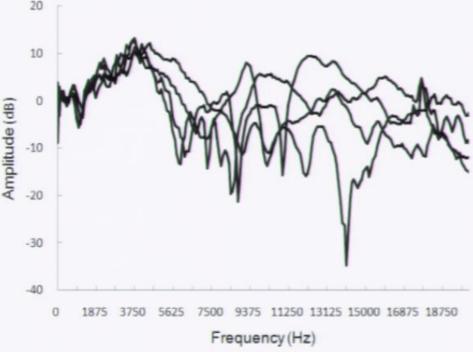
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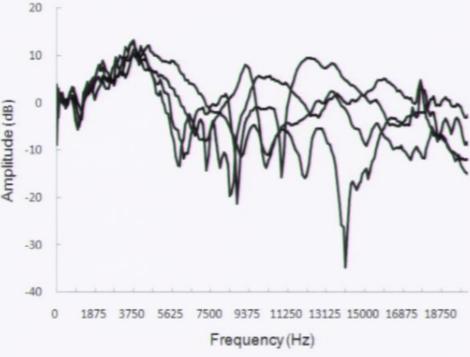
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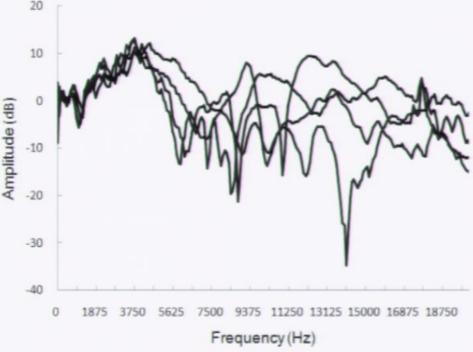
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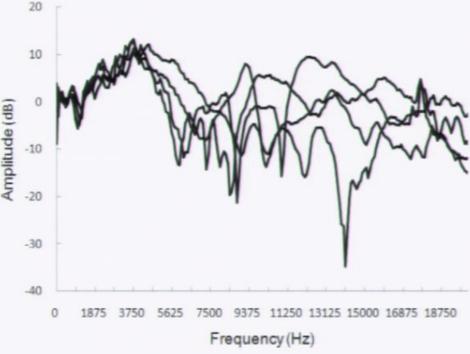
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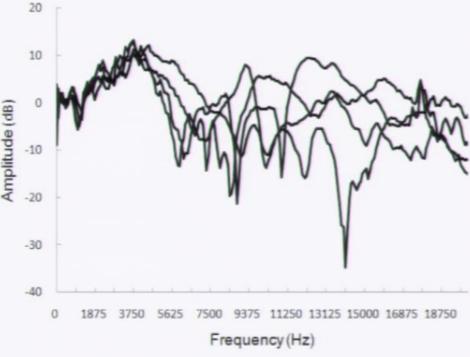
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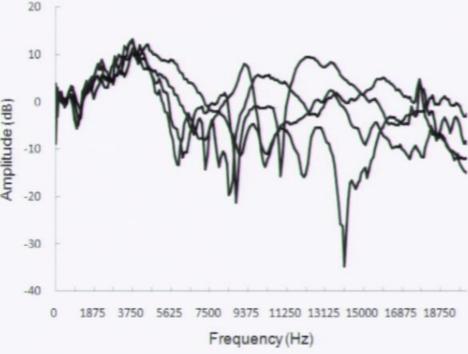
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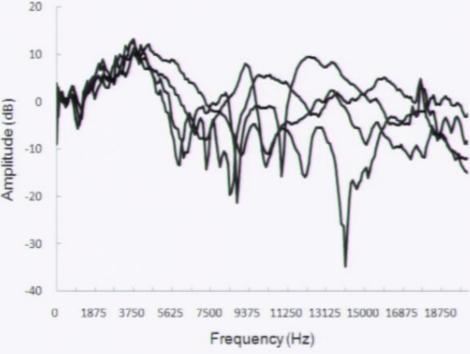
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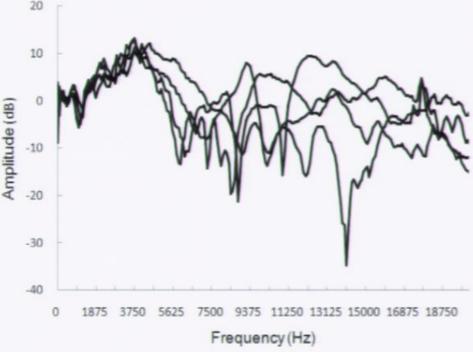
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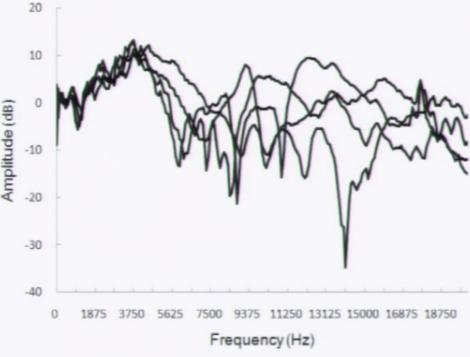
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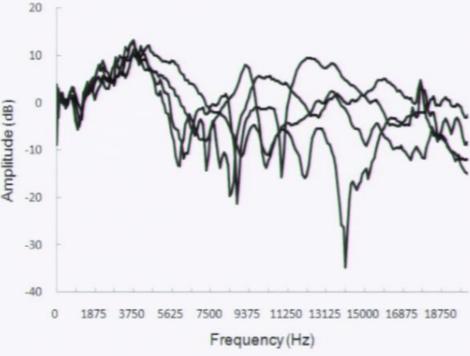
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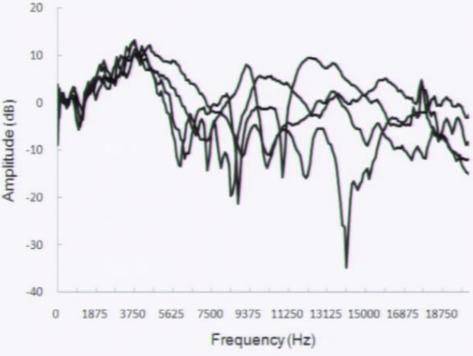
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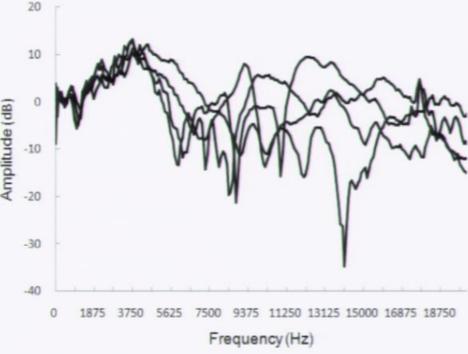
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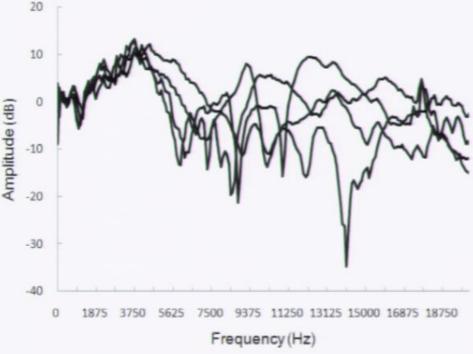
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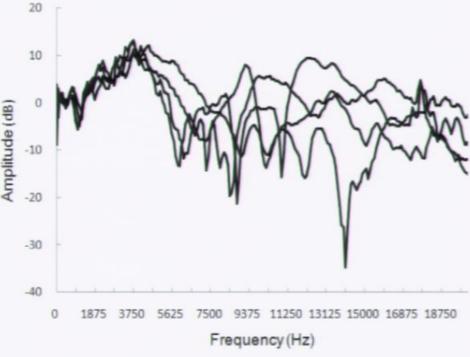
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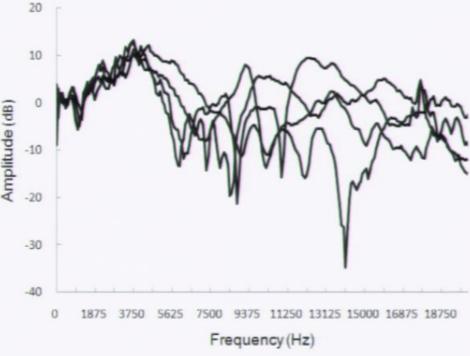
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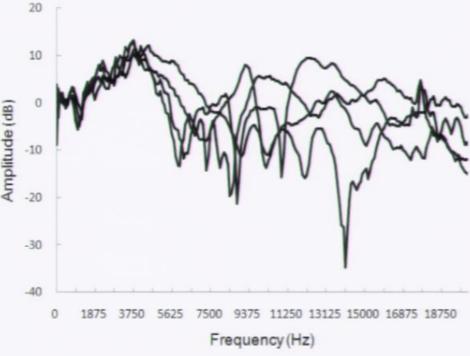
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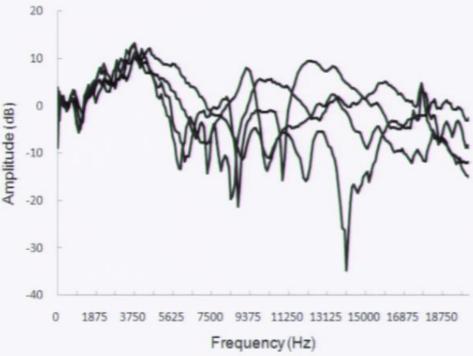
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"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 543/896

 Contribute spectral notches and peaks to HRTF

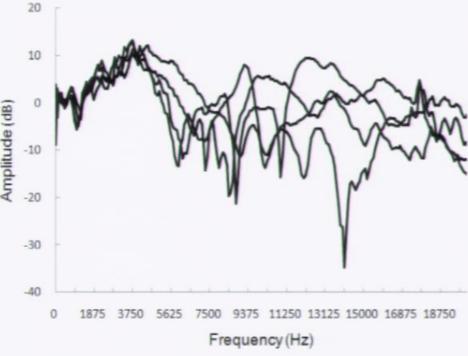
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 544/896

 Contribute spectral notches and peaks to HRTF

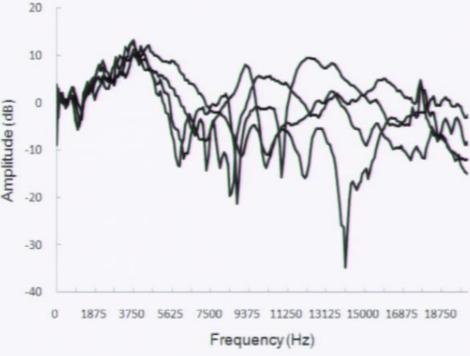
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 545/896

 Contribute spectral notches and peaks to HRTF

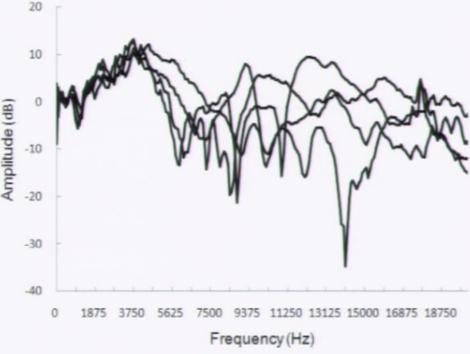
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 546/896

 Contribute spectral notches and peaks to HRTF

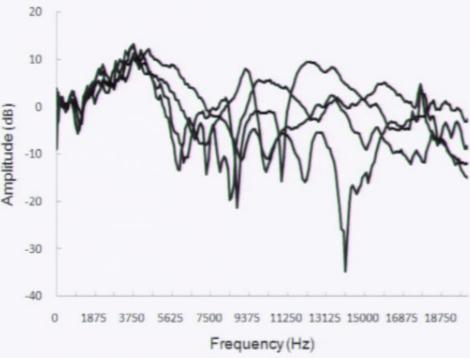
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 547/896

 Contribute spectral notches and peaks to HRTF

- Not analytically described
- Acts as a funnel a low frequencies

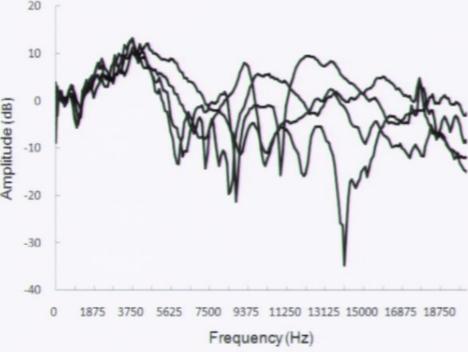


"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 548/896

 Contribute spectral notches and peaks to HRTF

Not analytically described

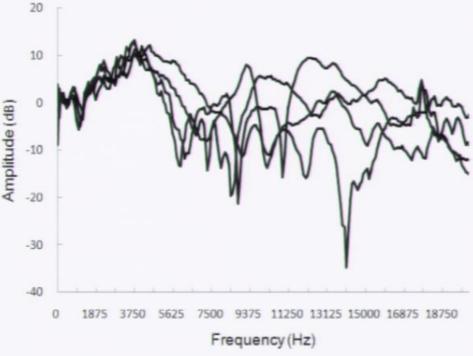
 Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 549/896

 Contribute spectral notches and peaks to HRTF

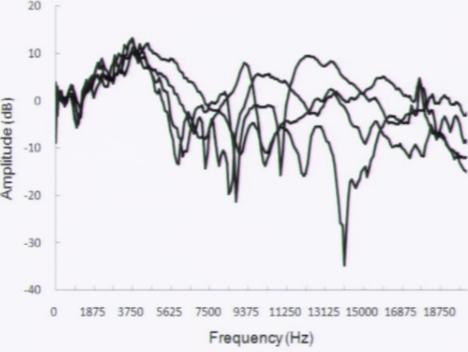
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 550/896

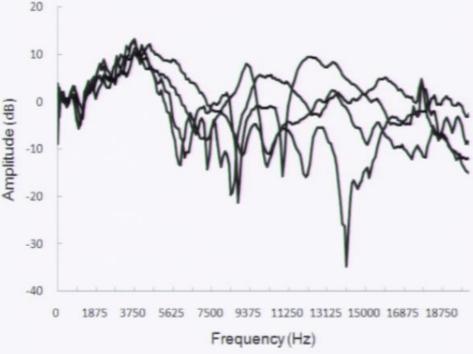
 Contribute spectral notches and peaks to HRTF

- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 551/896

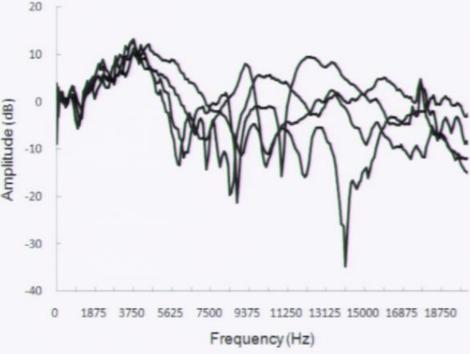
- Contribute spectral notches and peaks to HRTF
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 552/896

 Contribute spectral notches and peaks to HRTF

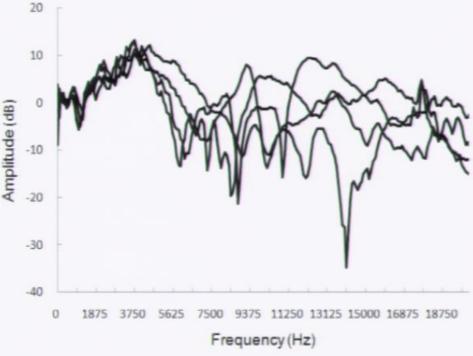
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 553/896

 Contribute spectral notches and peaks to HRTF

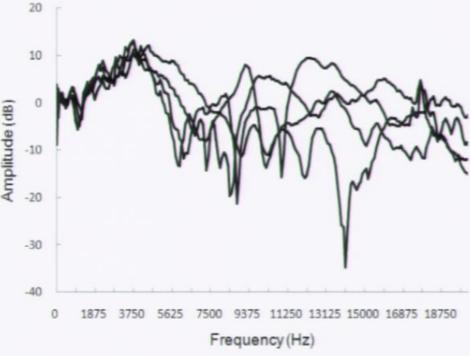
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 554/896

 Contribute spectral notches and peaks to HRTF

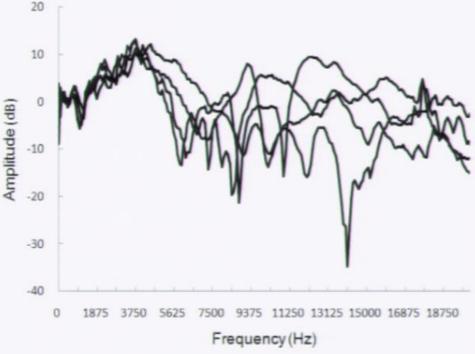
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 555/896

 Contribute spectral notches and peaks to HRTF

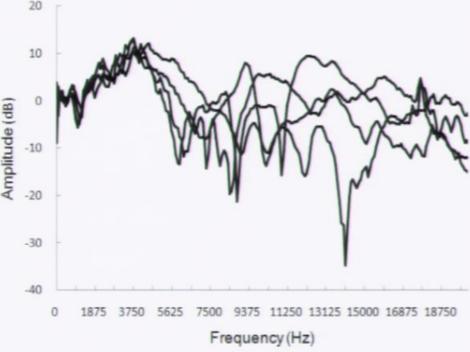
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 556/896

 Contribute spectral notches and peaks to HRTF

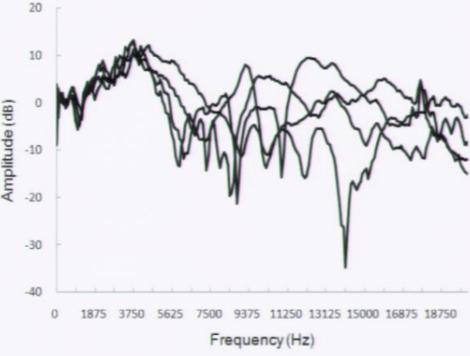
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 557/896

 Contribute spectral notches and peaks to HRTF

- Not analytically described
- Acts as a funnel a low frequencies

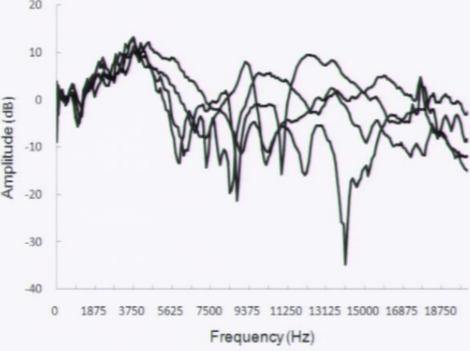


"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 558/896

 Contribute spectral notches and peaks to HRTF

Not analytically described

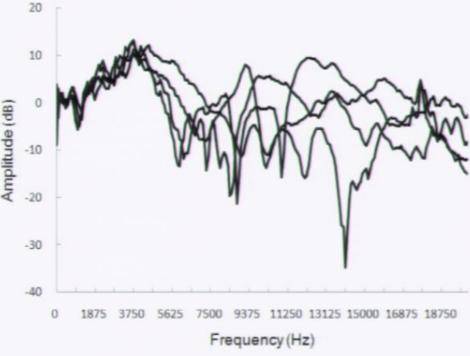
 Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 559/896

 Contribute spectral notches and peaks to HRTF

- Not analytically described
- Acts as a funnel a low frequencies



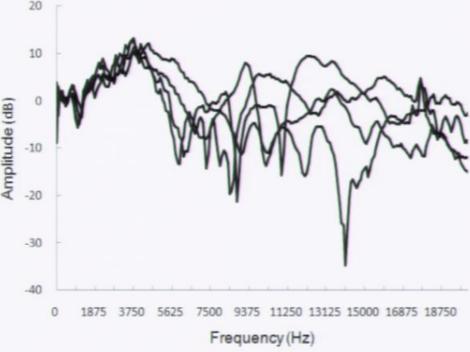
"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 560/896

Thank you

Pirsa: 10080005

 Contribute spectral notches and peaks to HRTF

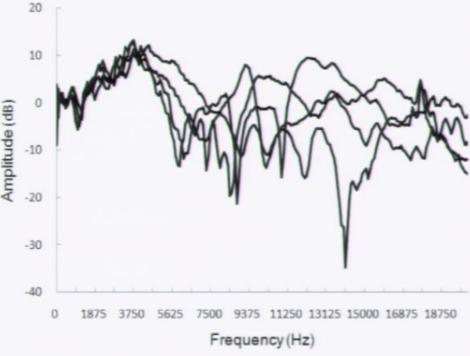
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 562/896

 Contribute spectral notches and peaks to HRTF

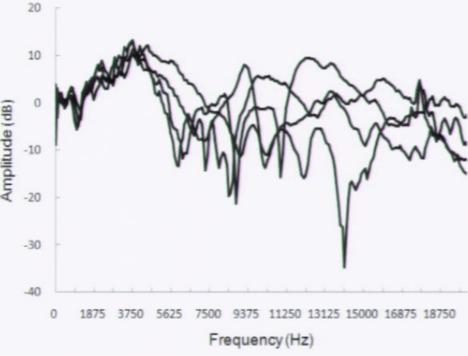
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 563/896

 Contribute spectral notches and peaks to HRTF

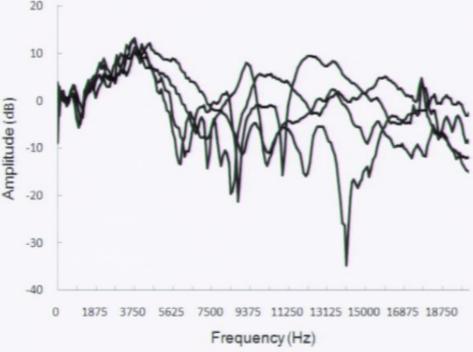
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 564/896

 Contribute spectral notches and peaks to HRTF

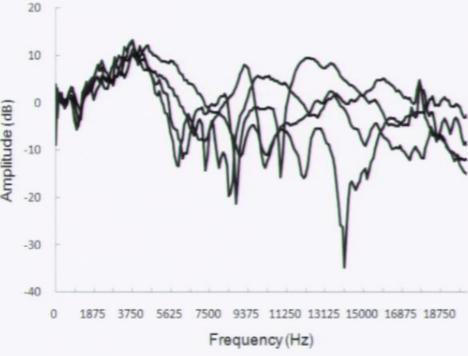
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 565/896

 Contribute spectral notches and peaks to HRTF

- Not analytically described
- Acts as a funnel a low frequencies

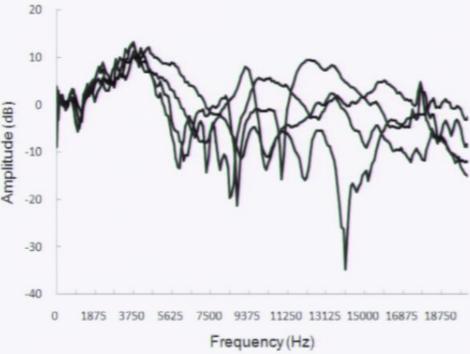


"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 566/896

 Contribute spectral notches and peaks to HRTF

Not analytically described

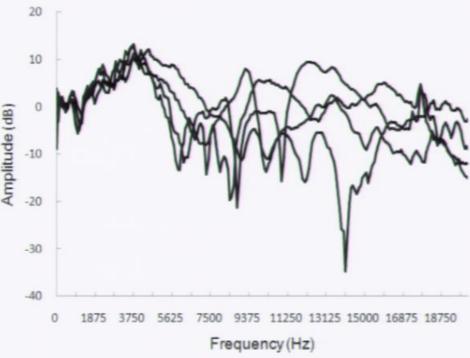
 Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 567/896

 Contribute spectral notches and peaks to HRTF

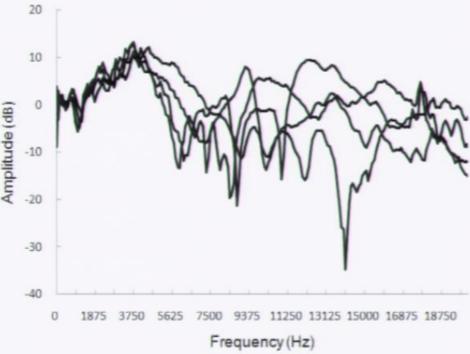
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 568/896

 Contribute spectral notches and peaks to HRTF

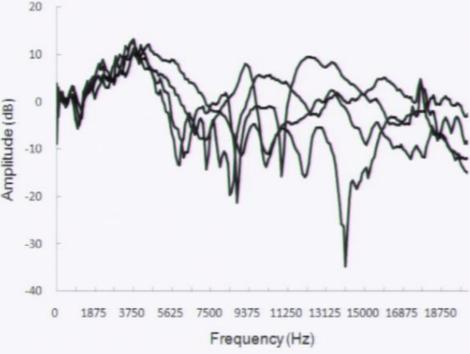
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 569/896

 Contribute spectral notches and peaks to HRTF

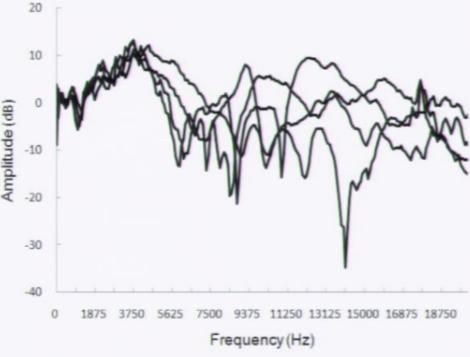
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 570/896

 Contribute spectral notches and peaks to HRTF

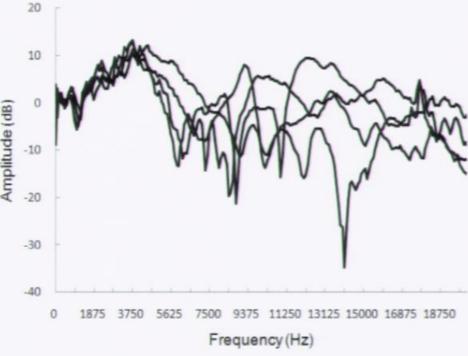
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 571/896

 Contribute spectral notches and peaks to HRTF

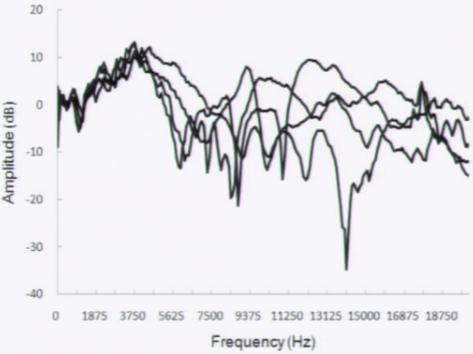
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 572/896

 Contribute spectral notches and peaks to HRTF

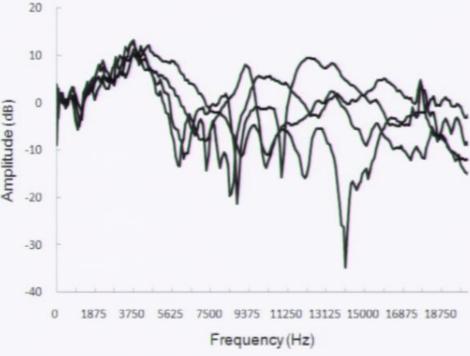
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 573/896

 Contribute spectral notches and peaks to HRTF

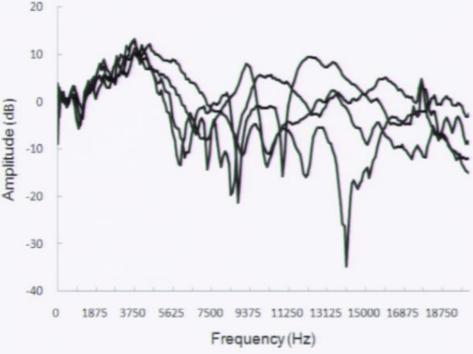
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 574/896

 Contribute spectral notches and peaks to HRTF

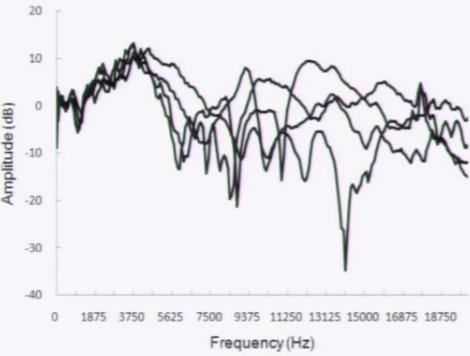
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 575/896

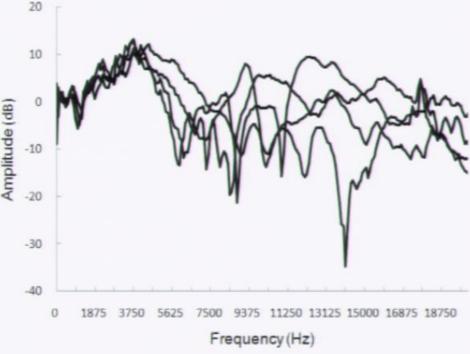
 Contribute spectral notches and peaks to HRTF

- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 576/896

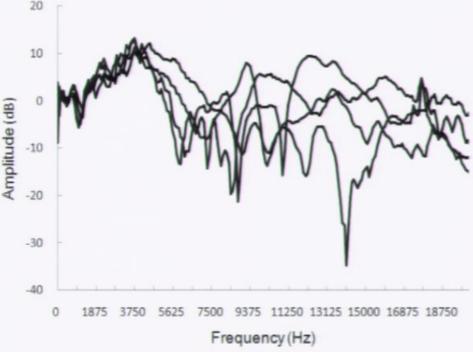
- Contribute spectral notches and peaks to HRTF
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 577/896

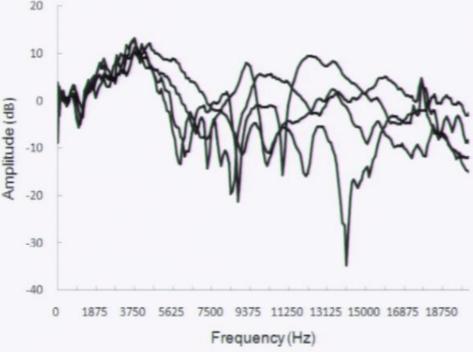
 Contribute spectral notches and peaks to HRTF

- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 578/896

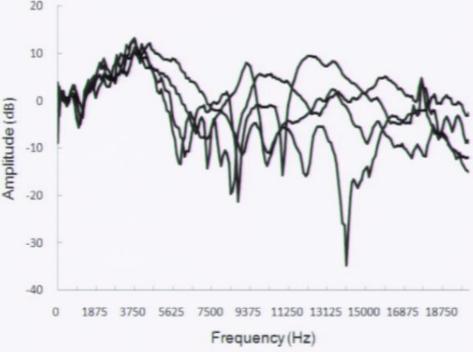
- Contribute spectral notches and peaks to HRTF
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 579/896

 Contribute spectral notches and peaks to HRTF

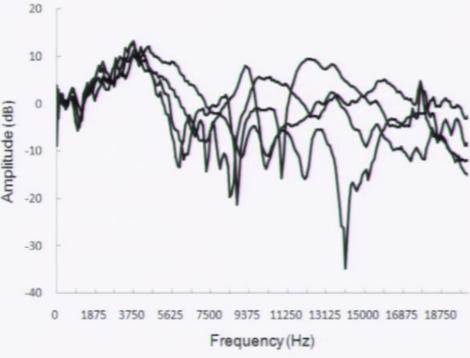
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 580/896

 Contribute spectral notches and peaks to HRTF

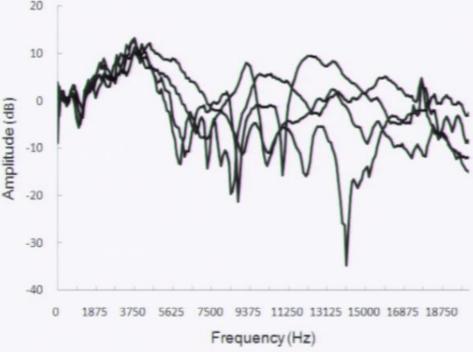
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 581/896

 Contribute spectral notches and peaks to HRTF

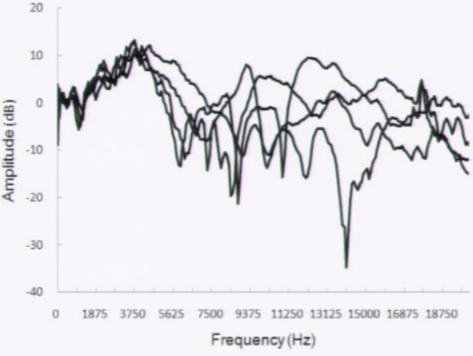
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 582/896

 Contribute spectral notches and peaks to HRTF

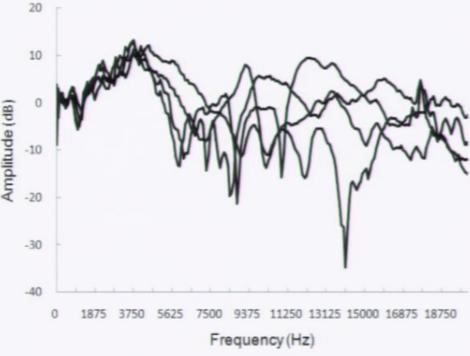
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 583/896

 Contribute spectral notches and peaks to HRTF

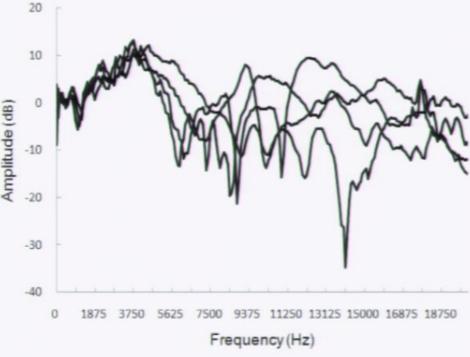
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 584/896

 Contribute spectral notches and peaks to HRTF

- Not analytically described
- Acts as a funnel a low frequencies

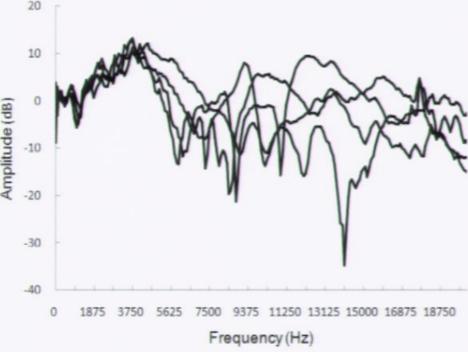


"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 585/896

 Contribute spectral notches and peaks to HRTF

Not analytically described

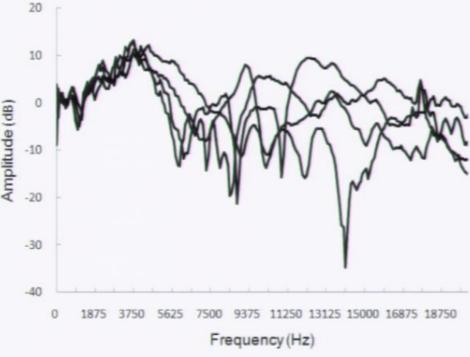
 Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 586/896

 Contribute spectral notches and peaks to HRTF

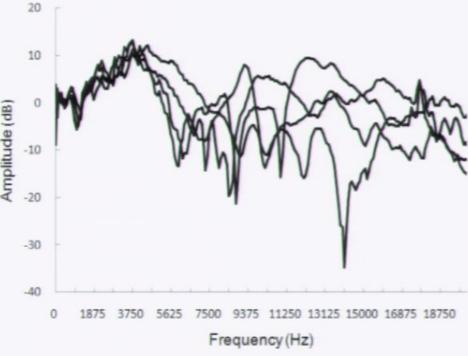
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 587/896

 Contribute spectral notches and peaks to HRTF

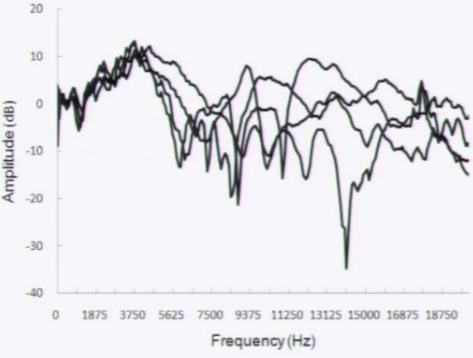
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 588/896

 Contribute spectral notches and peaks to HRTF

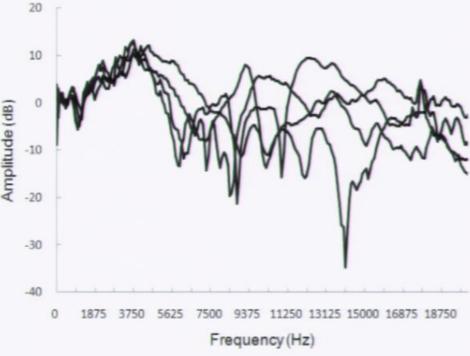
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 589/896

 Contribute spectral notches and peaks to HRTF

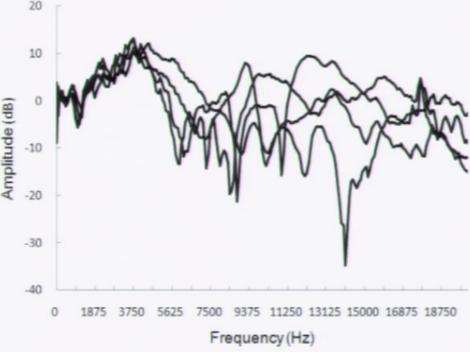
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 590/896

 Contribute spectral notches and peaks to HRTF

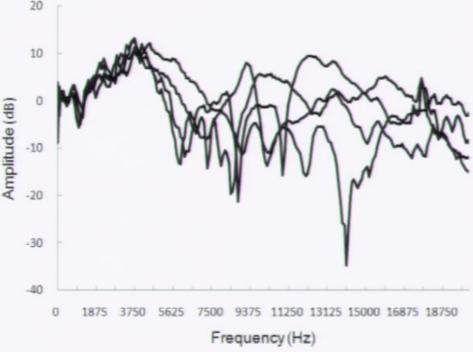
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 591/896

 Contribute spectral notches and peaks to HRTF

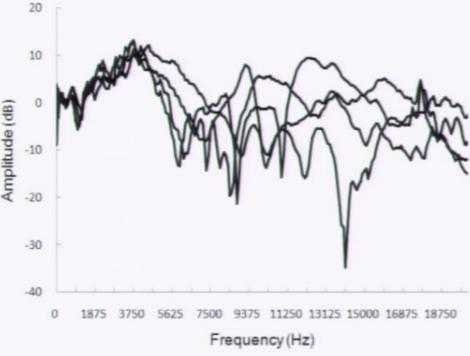
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 592/896

 Contribute spectral notches and peaks to HRTF

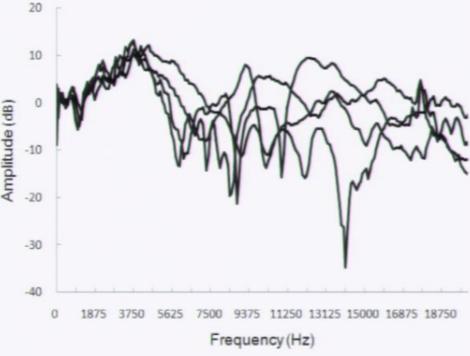
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 593/896

 Contribute spectral notches and peaks to HRTF

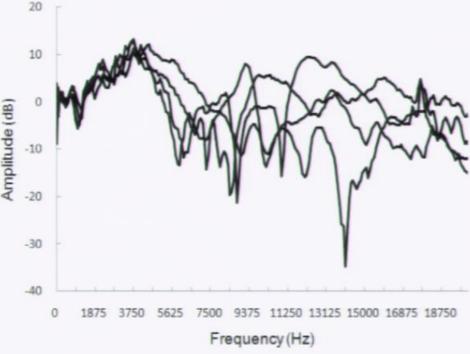
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 594/896

 Contribute spectral notches and peaks to HRTF

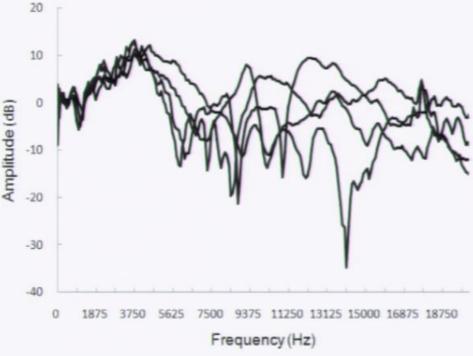
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 595/896

 Contribute spectral notches and peaks to HRTF

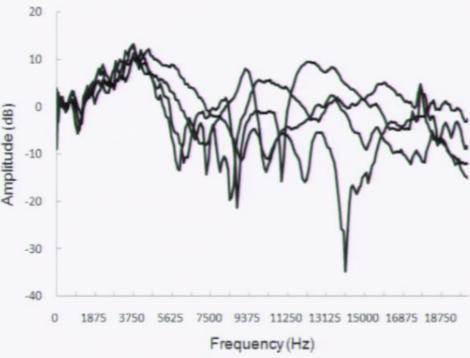
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 596/896

 Contribute spectral notches and peaks to HRTF

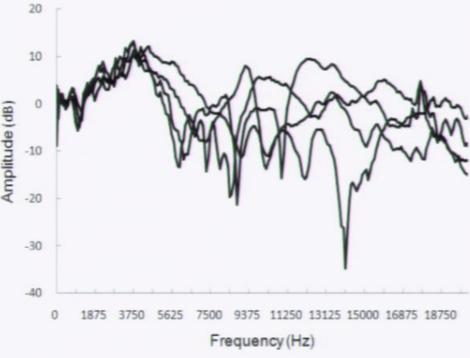
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 597/896

 Contribute spectral notches and peaks to HRTF

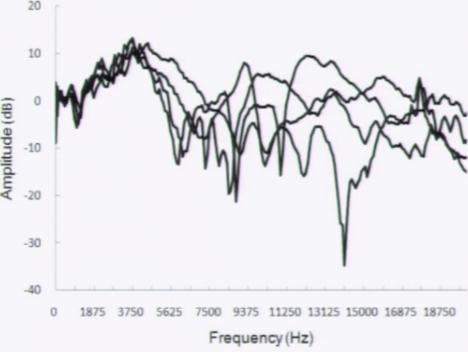
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 598/896

 Contribute spectral notches and peaks to HRTF

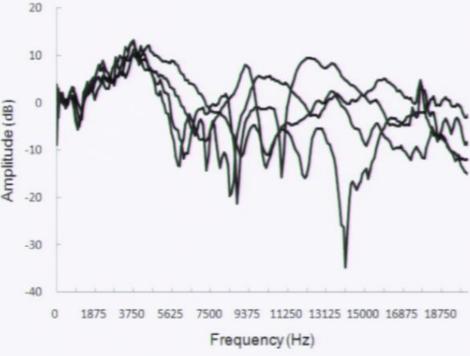
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 599/896

 Contribute spectral notches and peaks to HRTF

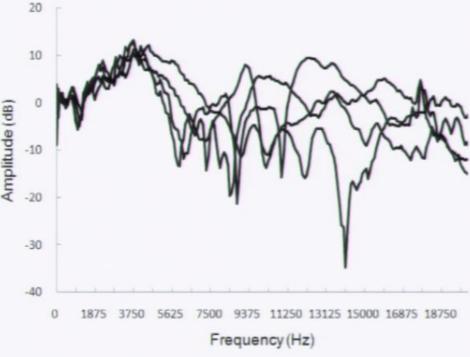
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 600/896

 Contribute spectral notches and peaks to HRTF

- Not analytically described
- Acts as a funnel a low frequencies

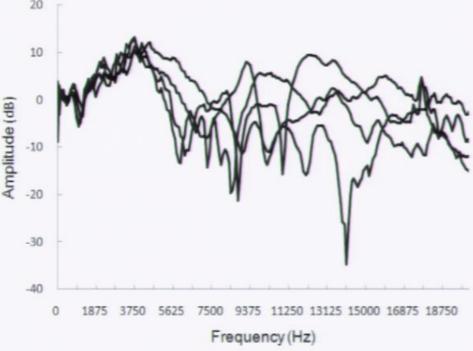


"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 601/896

 Contribute spectral notches and peaks to HRTF

Not analytically described

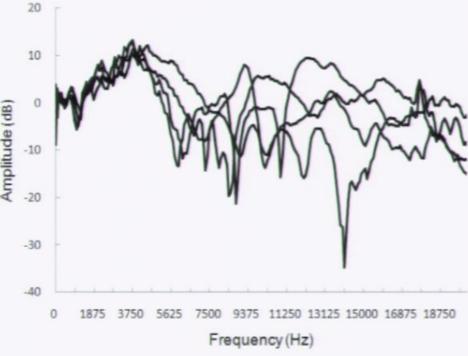
 Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 602/896

 Contribute spectral notches and peaks to HRTF

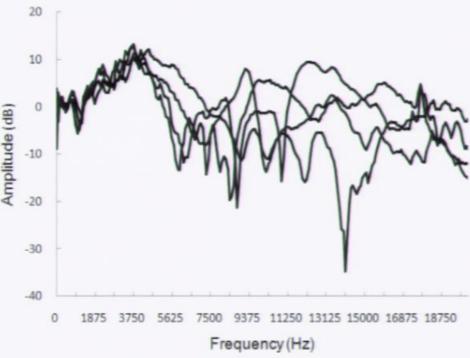
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 603/896

 Contribute spectral notches and peaks to HRTF

- Not analytically described
- Acts as a funnel a low frequencies

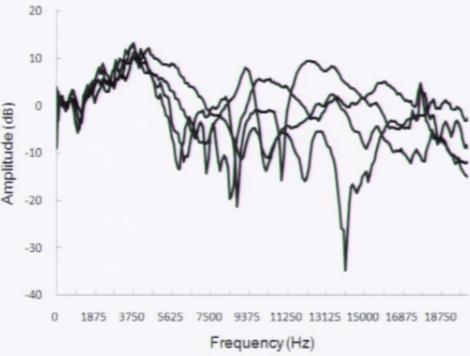


"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 604/896

 Contribute spectral notches and peaks to HRTF

Not analytically described

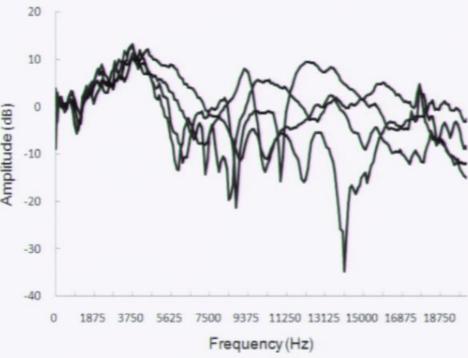
 Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 605/896

 Contribute spectral notches and peaks to HRTF

- Not analytically described
- Acts as a funnel a low frequencies

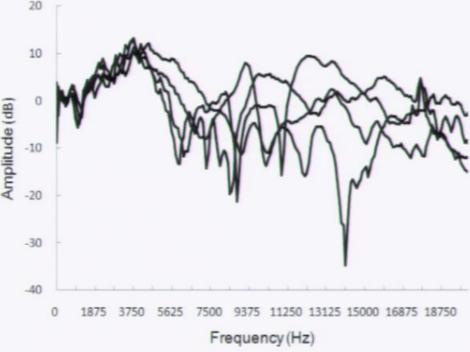


"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 606/896

 Contribute spectral notches and peaks to HRTF

Not analytically described

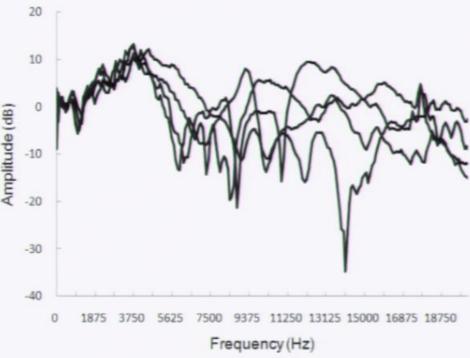
 Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 607/896

 Contribute spectral notches and peaks to HRTF

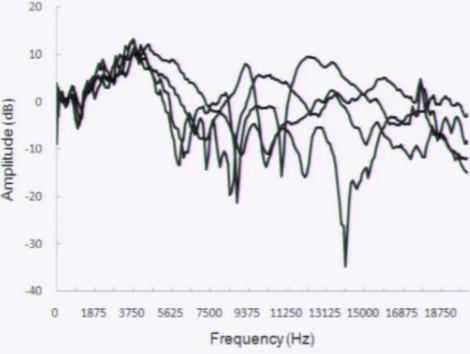
- Not analytically described
- Acts as a funnel a low frequencies



"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 608/896

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"An Approach to Individualization of head-related transfer functions based on the spectral cues for sound localization." Kazuhiro IIDA Page 609/896

The Ideal Body for Swimming (a Physics swan song) José Ricardo Oliveira Perimeter Scholars International 2010/11 Pirsa: 10080005

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Pirsa: 10080005

Outline

We will discuss the influence of body shape in swimming, namely how an adequate shape can reduce drag:

- description of the fluid-dynamic problem;
- qualitative remarks on the mechanisms of drag.

Pirsa: 10080005 Page 612/896

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Pirsa: 10080005 Page 614/896



Image: flyfishingnature.com



Image 123rf.com

Pirsa: 10080005 Page 615/896

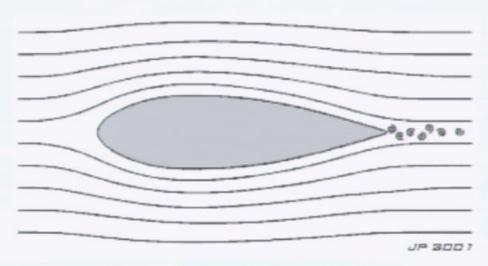


Image: Coilgun Systems website

 Clearly, if there is a point to the animals' body shapes, it is to reduce drag (as it slows you down, and requires a bigger effort to swim)

Pirsa: 10080005 Page 616/896

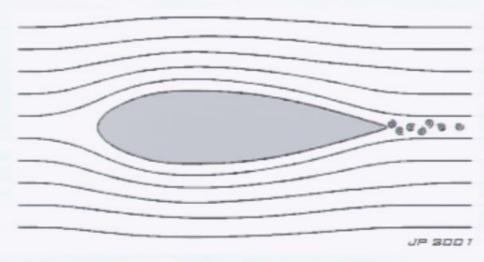


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Pirsa: 10080005 Page 617/896

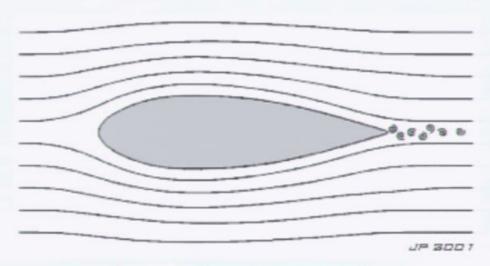


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Pirsa: 10080005 Page 618/896

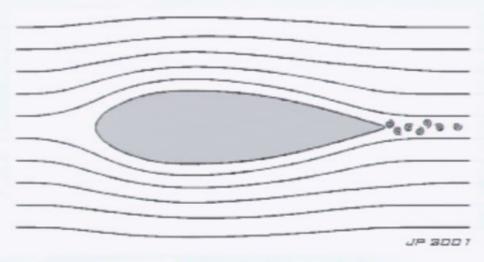


Image: Coilgun Systems website

 Clearly, if there is a point to the animals' body shapes, it is to reduce drag (as it slows you down, and requires a bigger effort to swim)

Pirsa: 10080005 Page 619/896

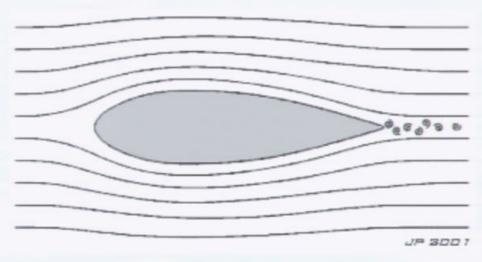


Image: Coilgun Systems website

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Pirsa: 10080005 Page 620/896

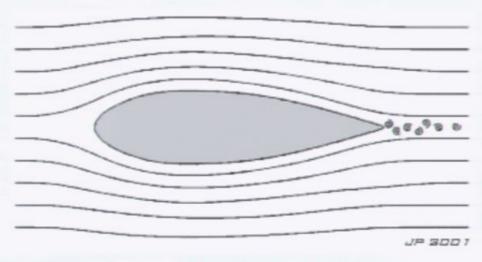


Image: Coilgun Systems website

 Clearly, if there is a point to the animals' body shapes, it is to reduce drag (as it slows you down, and requires a bigger effort to swim)

Pirsa: 10080005 Page 621/896

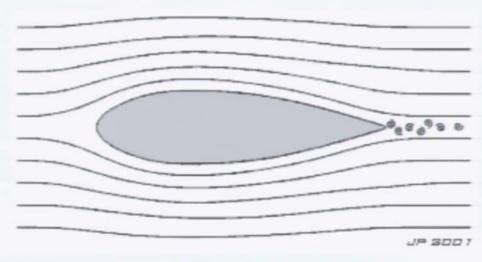


Image: Coilgun Systems website

 Clearly, if there is a point to the animals' body shapes, it is to reduce drag (as it slows you down, and requires a bigger effort to swim)

Pirsa: 10080005 Page 622/896

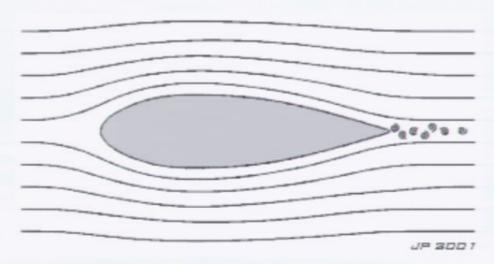


Image: Coilgun Systems website

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Pirsa: 10080005 Page 623/896

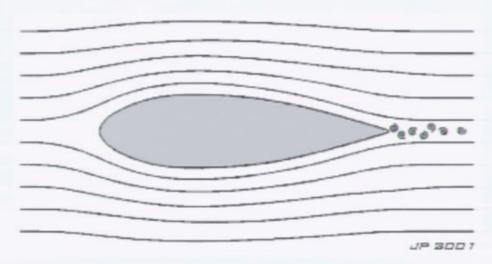


Image: Coilgun Systems website

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Pirsa: 10080005 Page 624/896

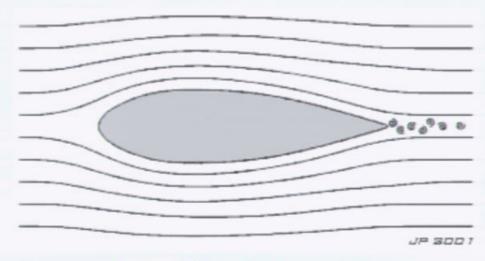


Image: Coilgun Systems website

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Pirsa: 10080005 Page 625/896

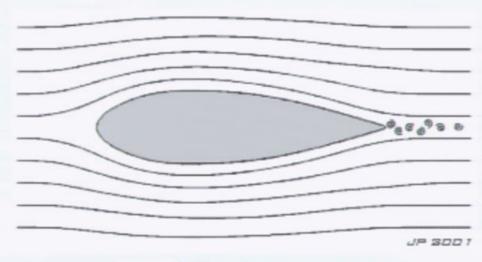
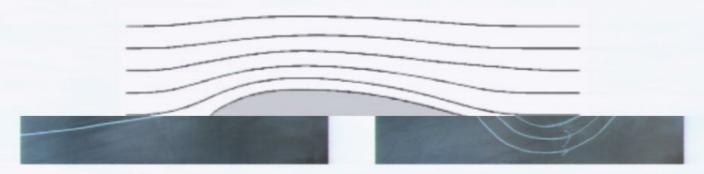


Image: Coilgun Systems website

 Clearly, if there is a point to the animals' body shapes, it is to reduce drag (as it slows you down, and requires a bigger effort to swim)

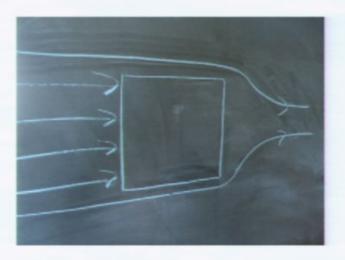
Pirsa: 10080005 Page 626/896

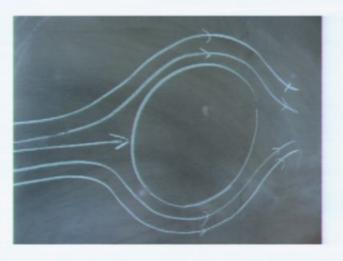


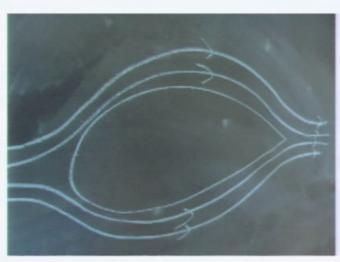


Pirsa: 10080005 Page 627/896

Let us try to gain some intuition on which shapes are more efficient:







Pirsa: 10080005 Page 628/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

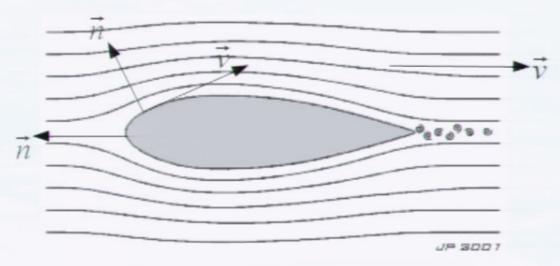


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
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Pirsa: 10080005 Page 629/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

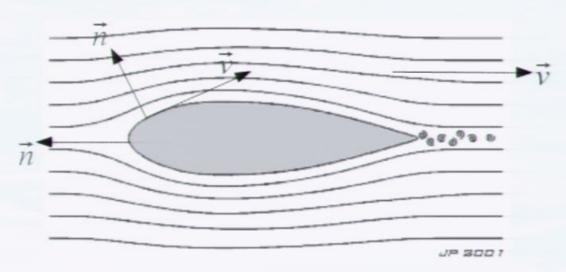


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
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Pirsa: 10080005 Page 630/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

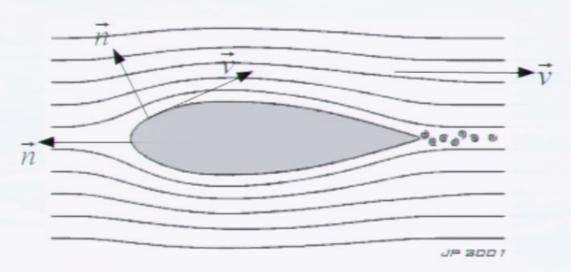


Image: Coilgun Systems website

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Pirsa: 10080005 Page 631/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

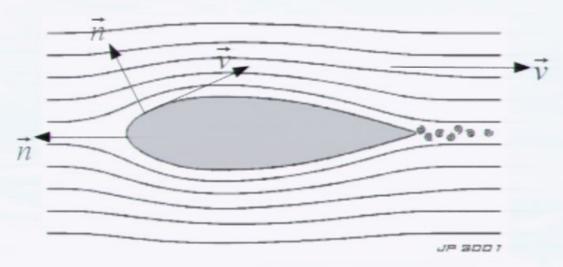


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
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Pirsa: 10080005 Page 632/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

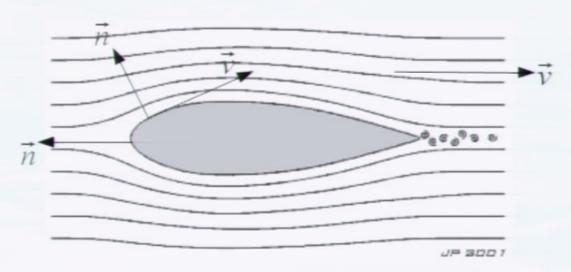


Image: Coilgun Systems website

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Pirsa: 10080005 Page 633/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

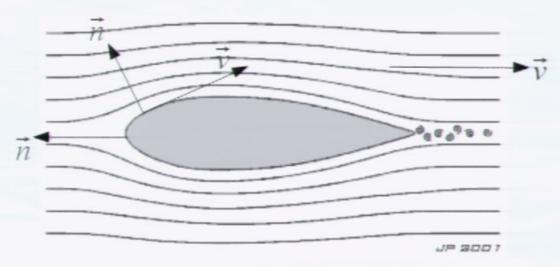


Image: Coilgun Systems website

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Pirsa: 10080005 Page 634/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

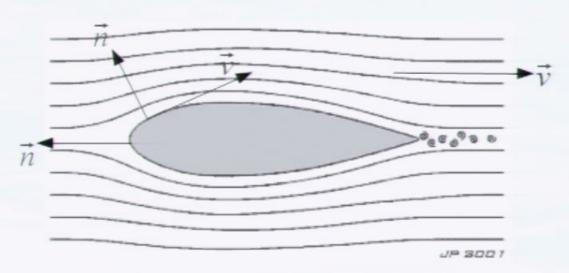


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
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Pirsa: 10080005 Page 635/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

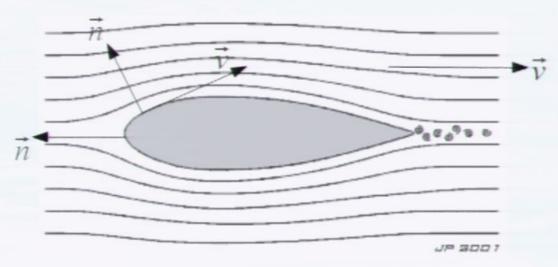


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
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Pirsa: 10080005 Page 636/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

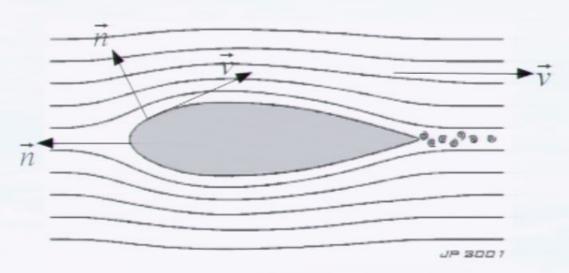


Image: Coilgun Systems website

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Pirsa: 10080005 Page 637/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

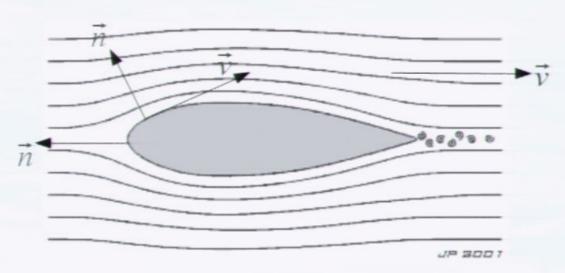


Image: Coilgun Systems website

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Pirsa: 10080005 Page 638/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

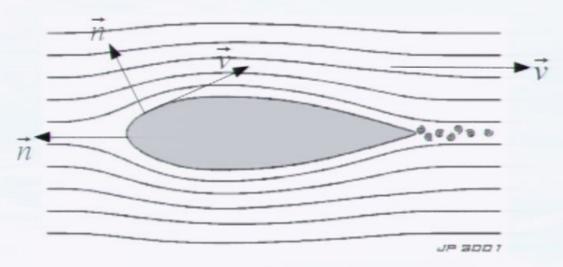


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
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Pirsa: 10080005 Page 639/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

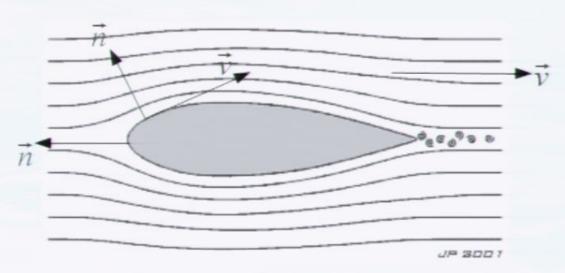


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
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Pirsa: 10080005 Page 640/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

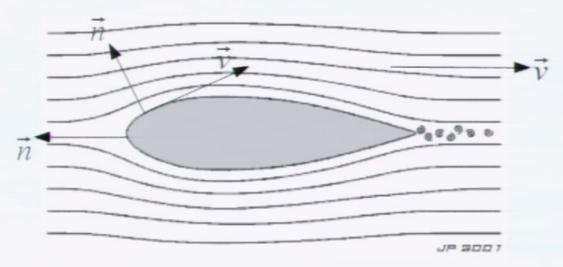


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
- In the surface, the normal component of velocity vanishes, $\vec{v} \cdot \vec{n} = 0$

Pirsa: 10080005 Page 641/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

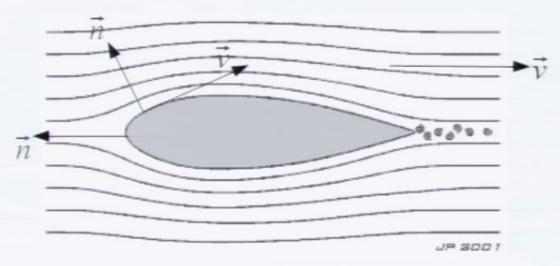


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
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Pirsa: 10080005 Page 642/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

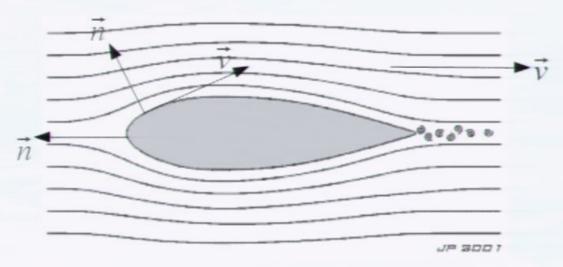


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
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Pirsa: 10080005 Page 643/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

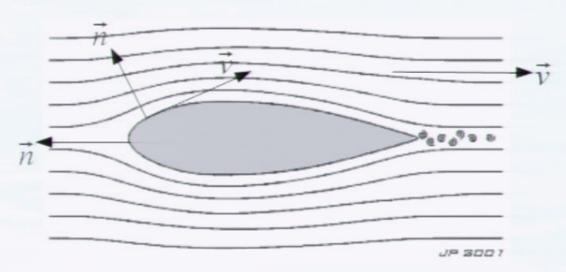


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, \$\vec{v} = v \vec{e}_x\$
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Pirsa: 10080005 Page 644/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

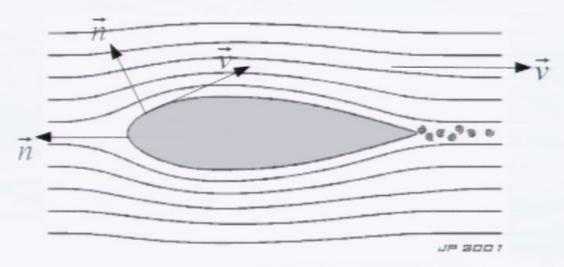


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
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Pirsa: 10080005 Page 645/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

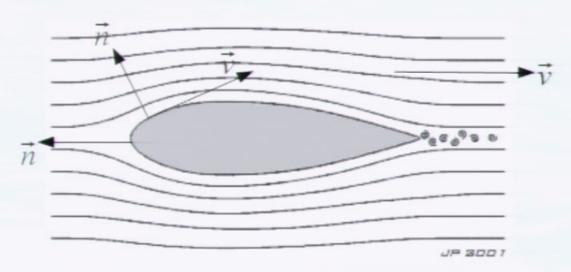


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
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Pirsa: 10080005 Page 646/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

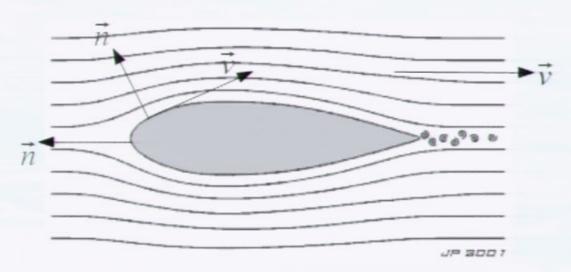


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
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Pirsa: 10080005 Page 647/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

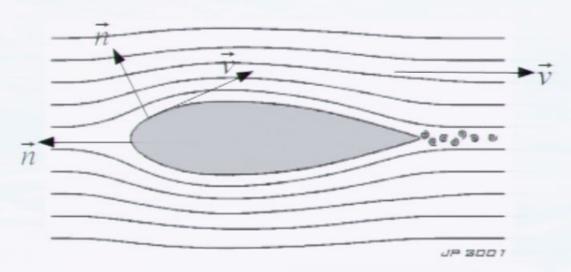


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
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Pirsa: 10080005 Page 648/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

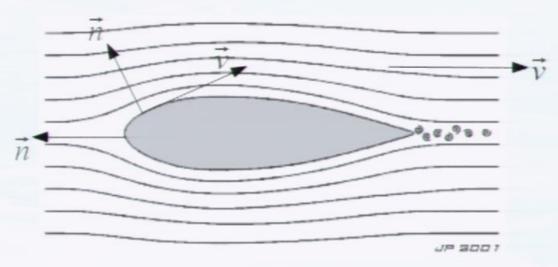


Image: Coilgun Systems website

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Pirsa: 10080005 Page 649/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

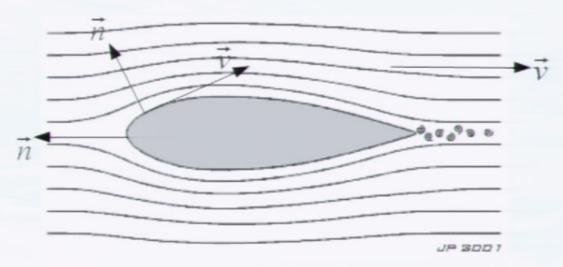


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
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Pirsa: 10080005 Page 650/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

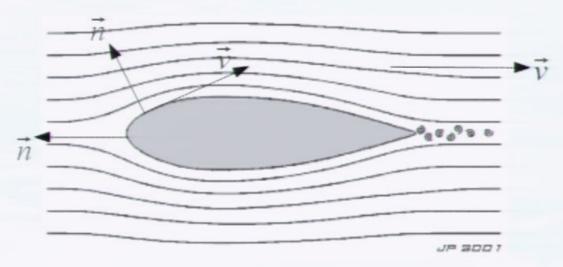


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Pirsa: 10080005 Page 651/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

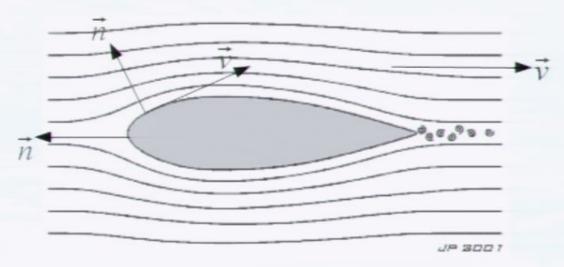


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Pirsa: 10080005 Page 652/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

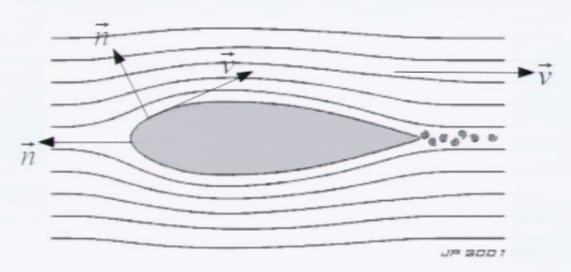


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Pirsa: 10080005 Page 653/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

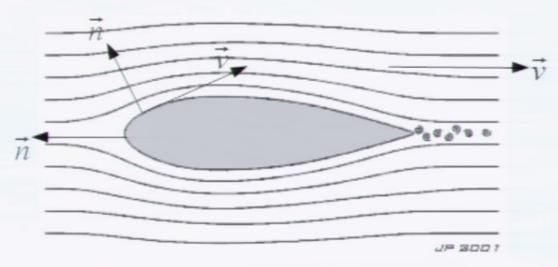


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Pirsa: 10080005 Page 654/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

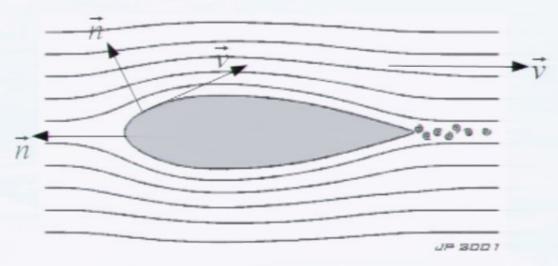


Image: Coilgun Systems website

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Pirsa: 10080005 Page 655/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

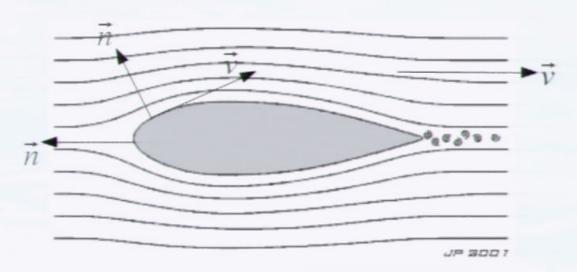


Image: Coilgun Systems website

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Pirsa: 10080005 Page 656/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

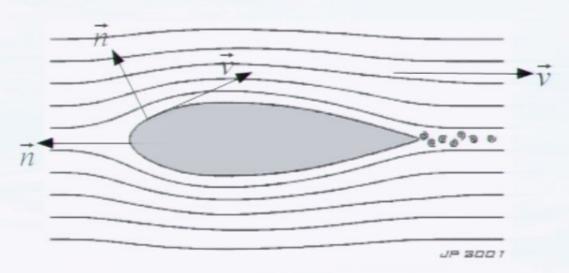


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- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
- In the surface, the normal component of velocity vanishes, $\vec{v} \cdot \vec{n} = 0$

Pirsa: 10080005 Page 657/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

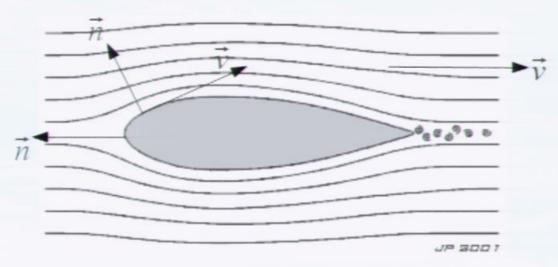


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
- In the surface, the normal component of velocity vanishes, $\vec{v} \cdot \vec{n} = 0$

Pirsa: 10080005 Page 658/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

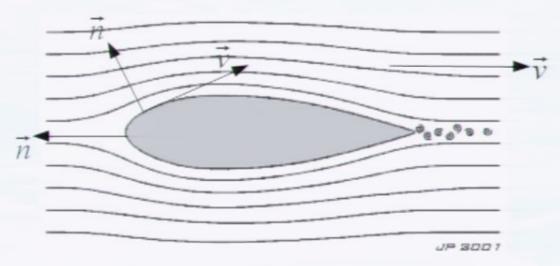


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, \$\vec{v} = v \vec{e}_x\$
- In the surface, the normal component of velocity vanishes, $\vec{v} \cdot \vec{n} = 0$

Pirsa: 10080005 Page 659/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

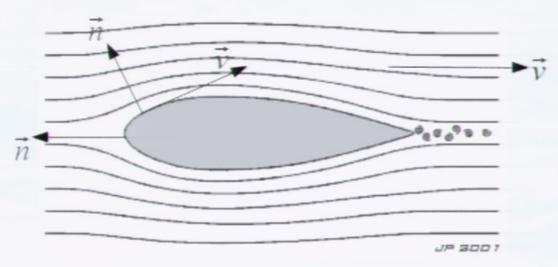


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
- In the surface, the normal component of velocity vanishes, $\vec{v} \cdot \vec{n} = 0$

Pirsa: 10080005 Page 660/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

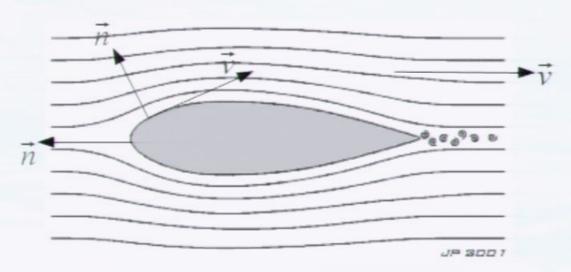


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
- In the surface, the normal component of velocity vanishes, $\vec{v} \cdot \vec{n} = 0$

Pirsa: 10080005 Page 661/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

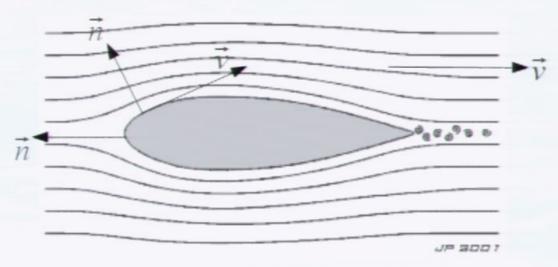


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
- In the surface, the normal component of velocity vanishes, $\vec{v} \cdot \vec{n} = 0$

Pirsa: 10080005 Page 662/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

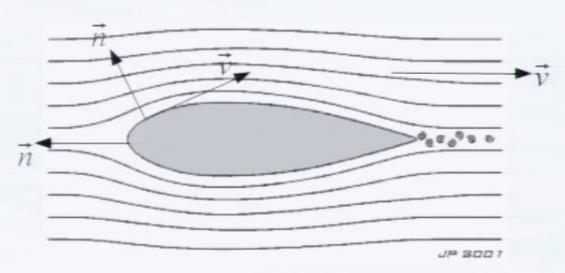


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
- In the surface, the normal component of velocity vanishes, $\vec{v} \cdot \vec{n} = 0$

Pirsa: 10080005 Page 663/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

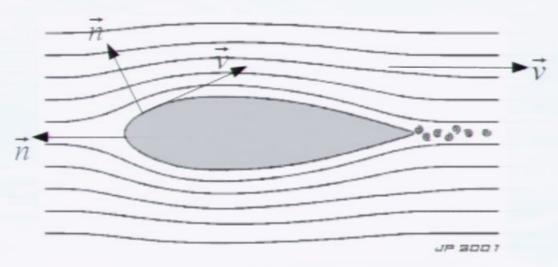


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
- In the surface, the normal component of velocity vanishes, $\vec{v} \cdot \vec{n} = 0$

Pirsa: 10080005 Page 664/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

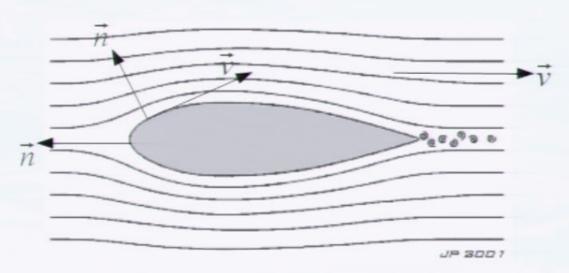


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
- In the surface, the normal component of velocity vanishes, $\vec{v} \cdot \vec{n} = 0$

Pirsa: 10080005 Page 665/896

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

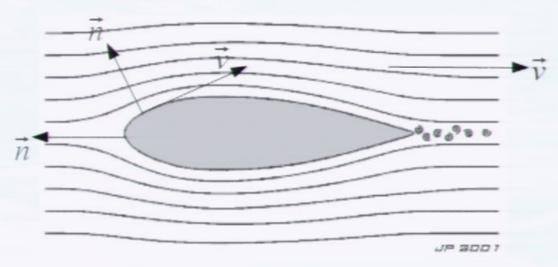


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
- In the surface, the normal component of velocity vanishes, $\vec{v} \cdot \vec{n} = 0$

Pirsa: 10080005 Page 666/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 100800005

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 668/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 669/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 670/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 671/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 672/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 673/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 674/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 675/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 676/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 677/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

PIIsa: 10080005

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
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$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 679/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{sunface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 681/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 682/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 683/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 684/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 685/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{sunface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 686/

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 687/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

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$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 688/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

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$$\vec{F} = \int_{sunface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 689/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{sunface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 690/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 691/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
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$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 693/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
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$$\vec{F} = \int_{sunface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 694/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 695/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 696/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

- Boundary conditions are given by velocity constraints at infinity and body surface.
- Given a solution, one can compute the net force exerted on the body:

$$\vec{F} = \int_{surface} \left(-\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{v} \right) \cdot \vec{n} \, dS$$

and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 697/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

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Pirsa: 10080005 Page 698/896

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Pirsa: 10080005 Page 699/896

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Pirsa: 10080005 Page 700/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

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Pirsa: 10080005 Page 701/896

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$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
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Pirsa: 10080005 Page 702/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
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and by comparing drag forces, determine the most efficient shape. Easy, right?

Pirsa: 10080005 Page 703/896

 Flow dynamics is described by the Navier-Stokes equations, together with the continuity equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{v} \nabla^2 \mathbf{v}$$
$$\nabla \cdot \mathbf{v} = 0$$

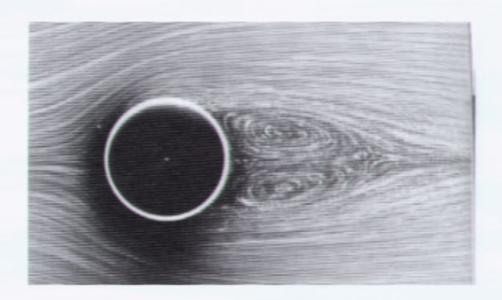
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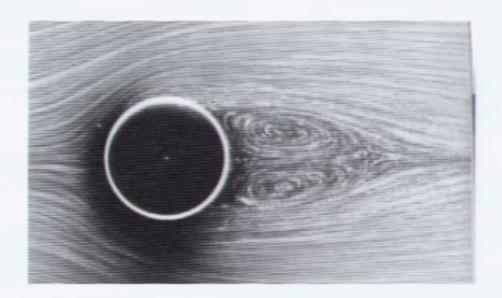
Pirsa: 10080005 Page 704/896

We can, however, obtain some qualitative insight, verifiable both by experiment and numerical simulations.



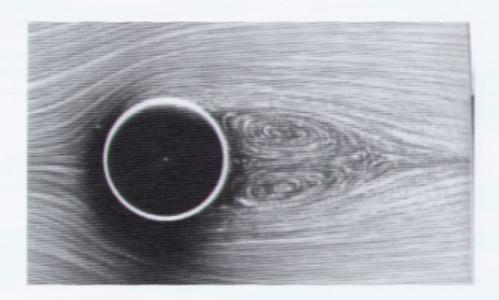
Pirsa: 10080005 Page 705/896

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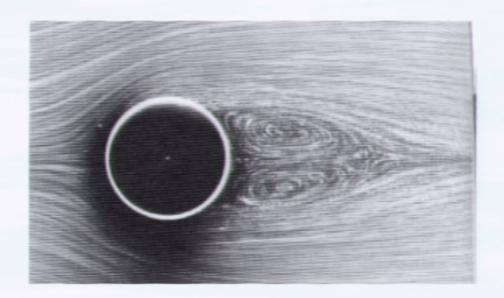
Pirsa: 10080005 Page 706/896

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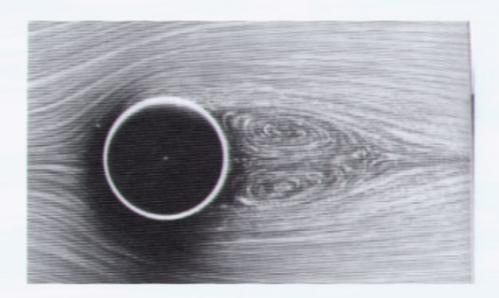
Pirsa: 10080005 Page 707/896

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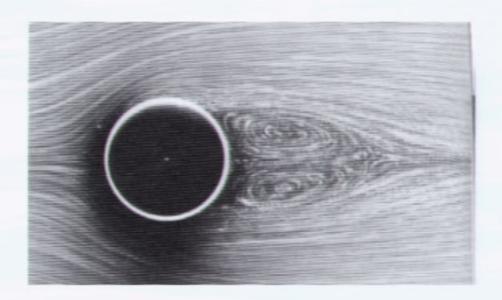
Pirsa: 10080005 Page 708/896

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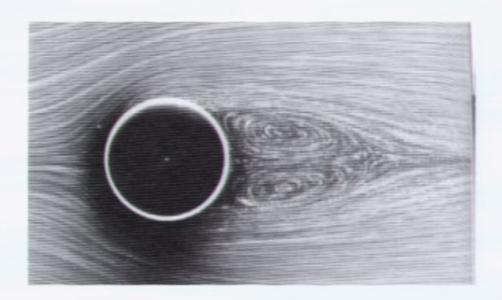
Pirsa: 10080005 Page 709/896

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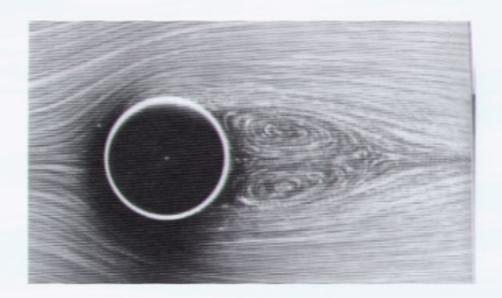
Pirsa: 10080005 Page 710/896

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Pirsa: 10080005 Page 711/896

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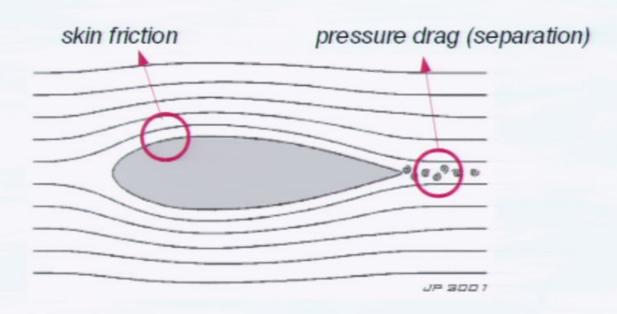


Pirsa: 10080005 Page 712/896

Principle: In low-viscosity fluids, internal friction is only appreciable in a thin region surrounding the boundaries, the boundary layer.

This results in two different sources of drag:

- Skin friction;
- Pressure drag.

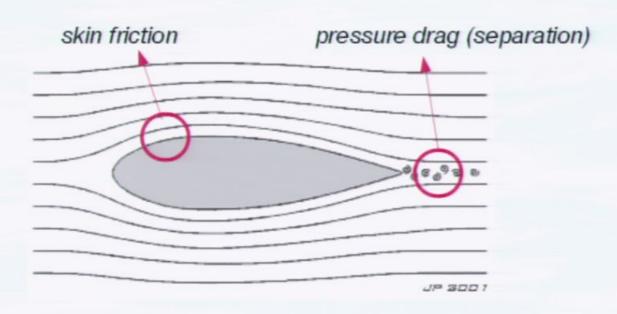


Pirsa: 10080005 Page 713/896

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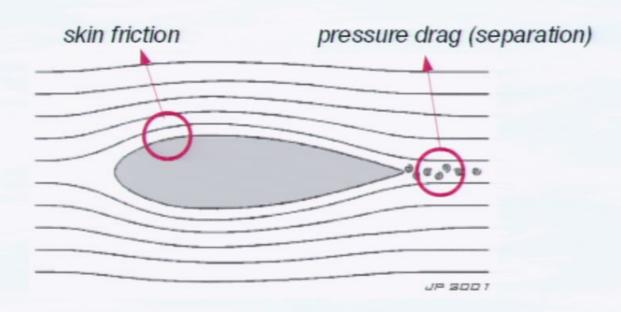


Pirsa: 10080005 Page 714/896

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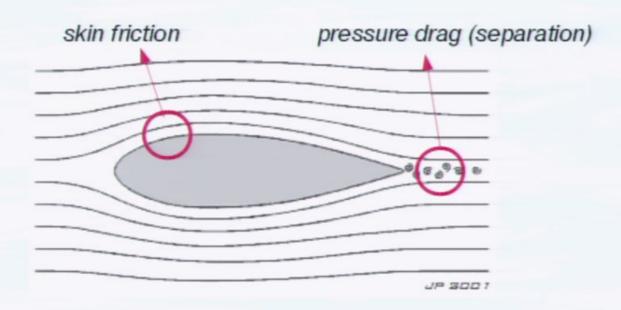


Pirsa: 10080005 Page 715/896

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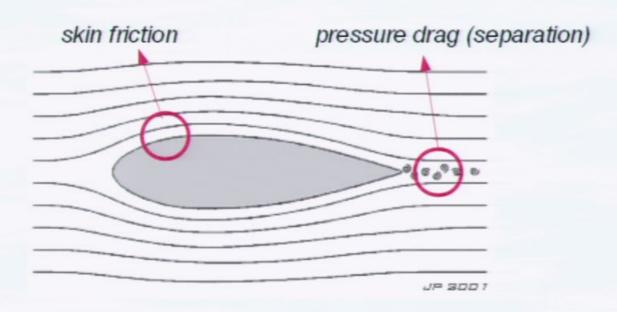


Pirsa: 10080005 Page 716/896

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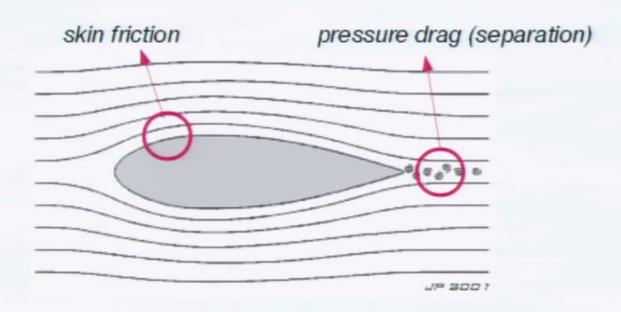


Pirsa: 10080005 Page 717/896

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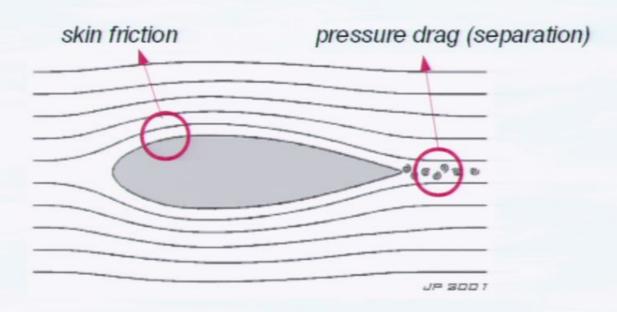


Pirsa: 10080005 Page 718/896

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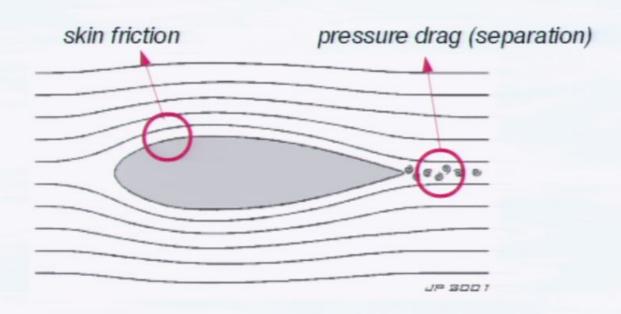


Pirsa: 10080005 Page 719/896

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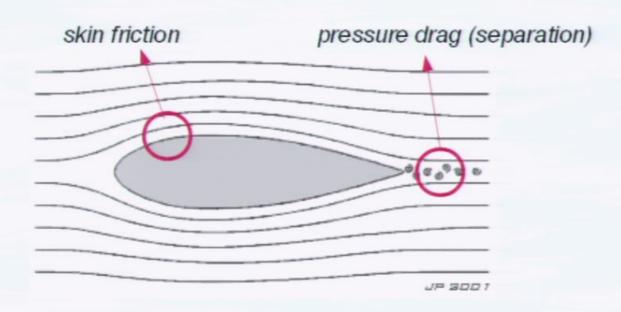


Pirsa: 10080005 Page 720/896

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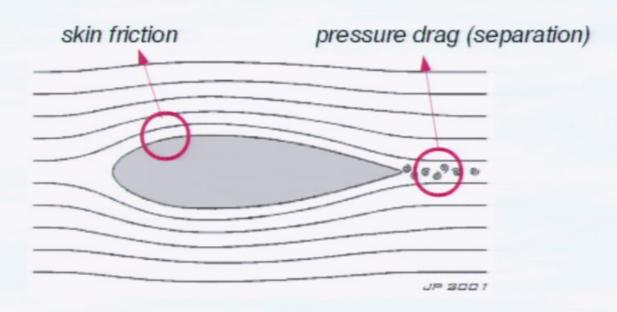


Pirsa: 10080005 Page 721/896

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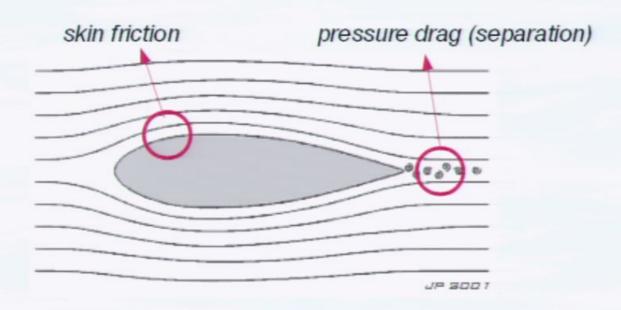


Pirsa: 10080005 Page 722/896

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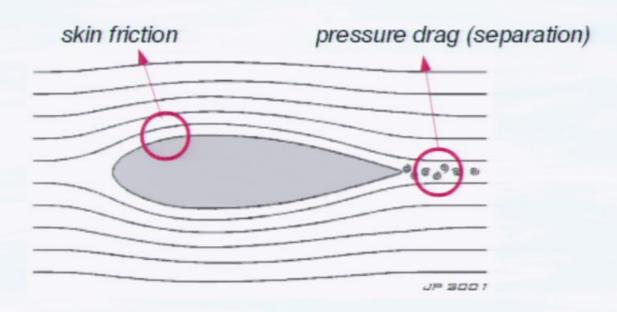


Pirsa: 10080005

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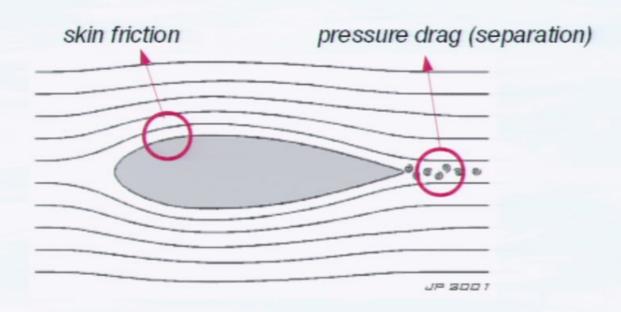


Pirsa: 10080005 Page 724/896

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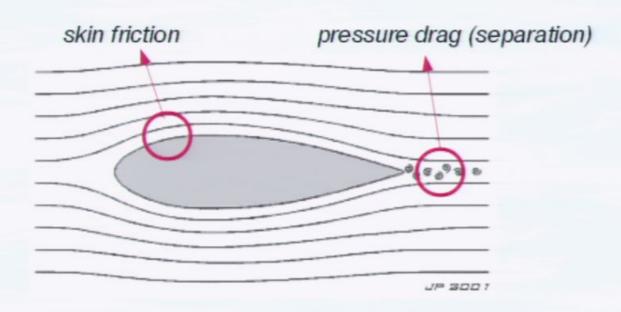


Pirsa: 10080005 Page 725/896

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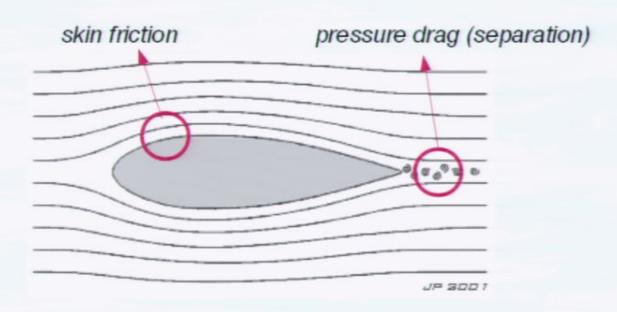


Pirsa: 10080005 Page 726/896

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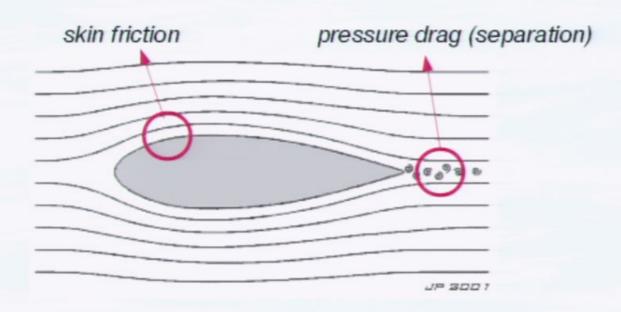


Pirsa: 10080005 Page 727/896

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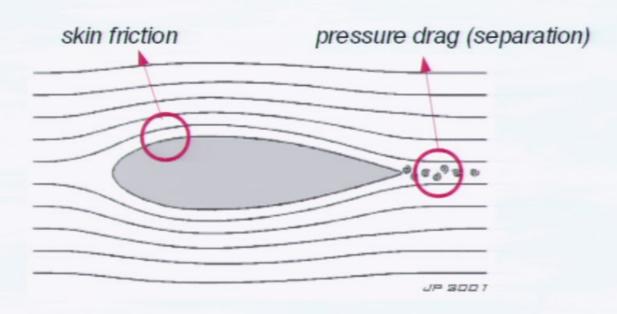


Pirsa: 10080005 Page 728/896

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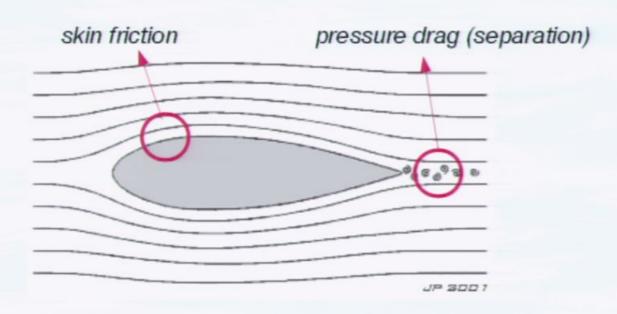


Pirsa: 10080005 Page 729/896

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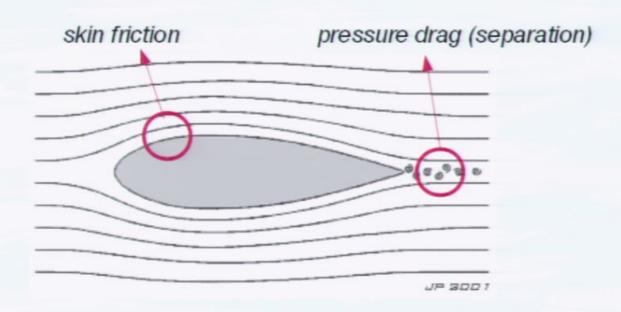


Pirsa: 10080005 Page 730/896

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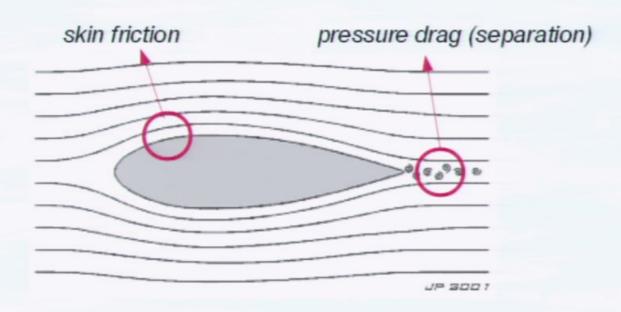


Pirsa: 10080005 Page 731/896

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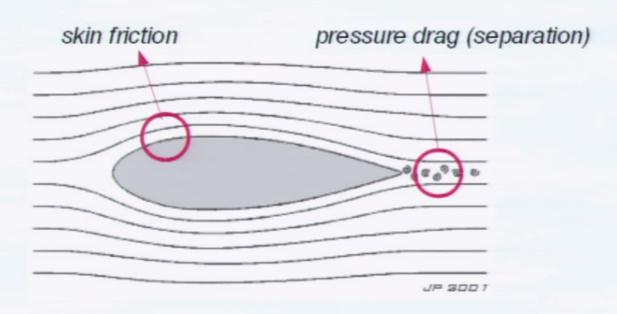


Pirsa: 10080005 Page 732/896

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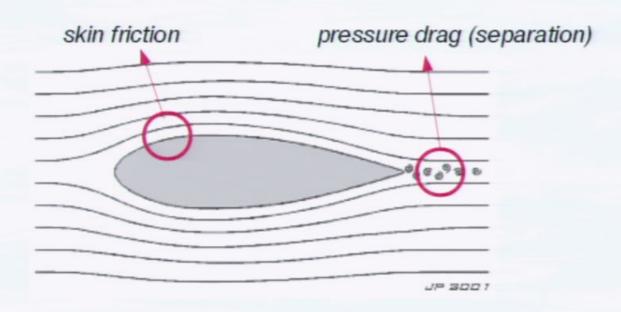


Pirsa: 10080005 Page 733/896

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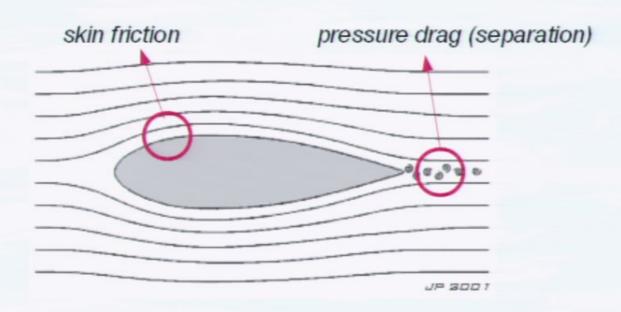


Pirsa: 10080005

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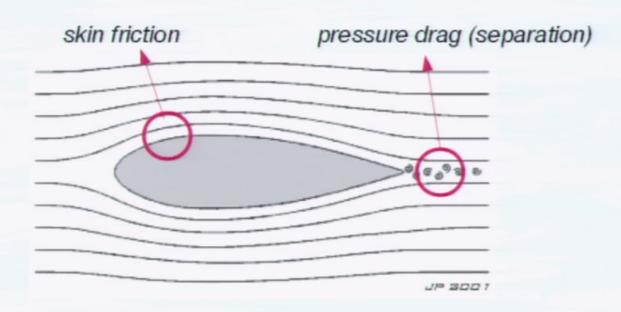


Pirsa: 10080005 Page 735/896

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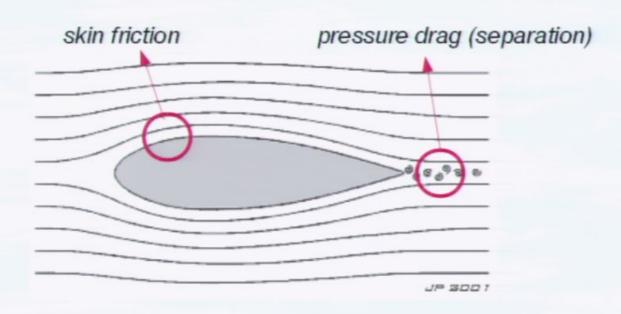


Pirsa: 10080005 Page 736/896

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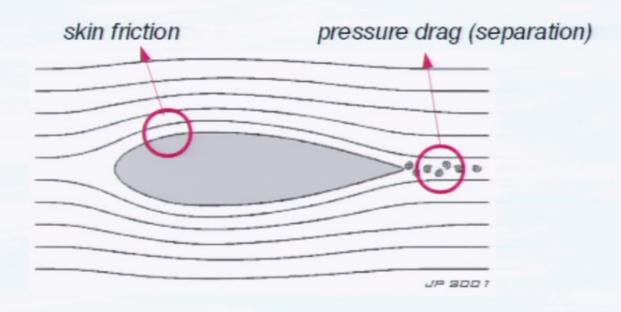


Pirsa: 10080005 Page 737/896

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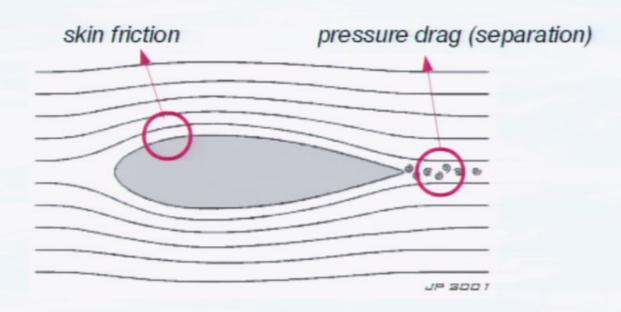


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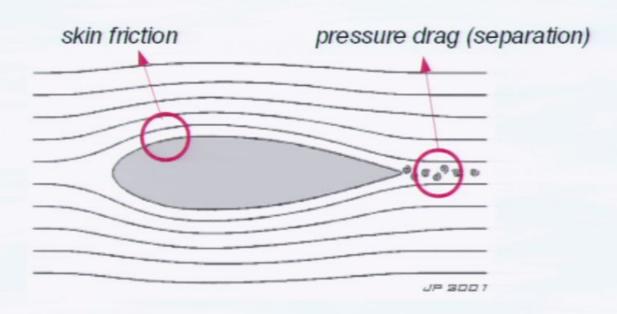


Pirsa: 10080005

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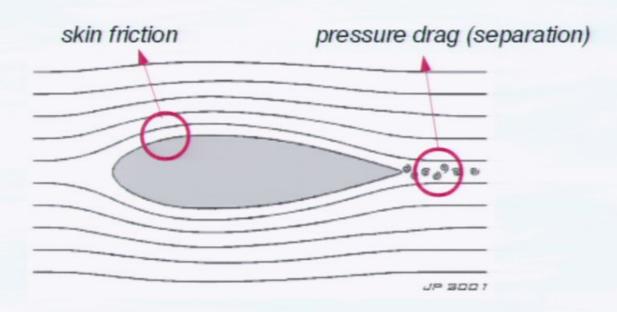


Pirsa: 10080005 Page 740/896

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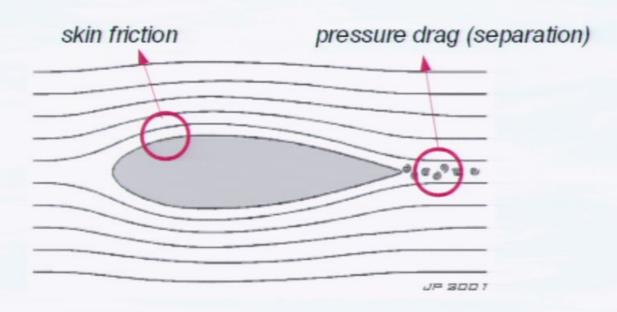


Pirsa: 10080005 Page 741/896

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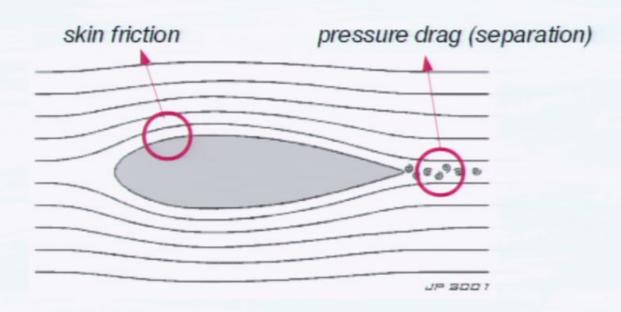


Pirsa: 10080005 Page 742/896

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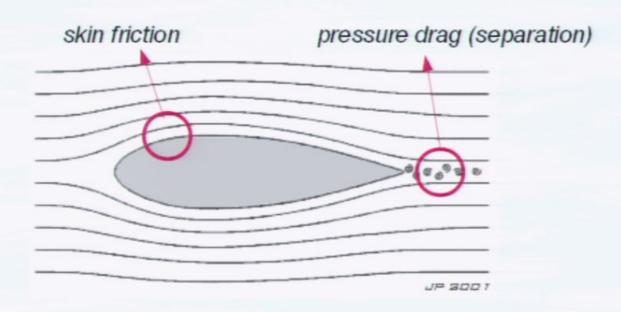


Pirsa: 10080005

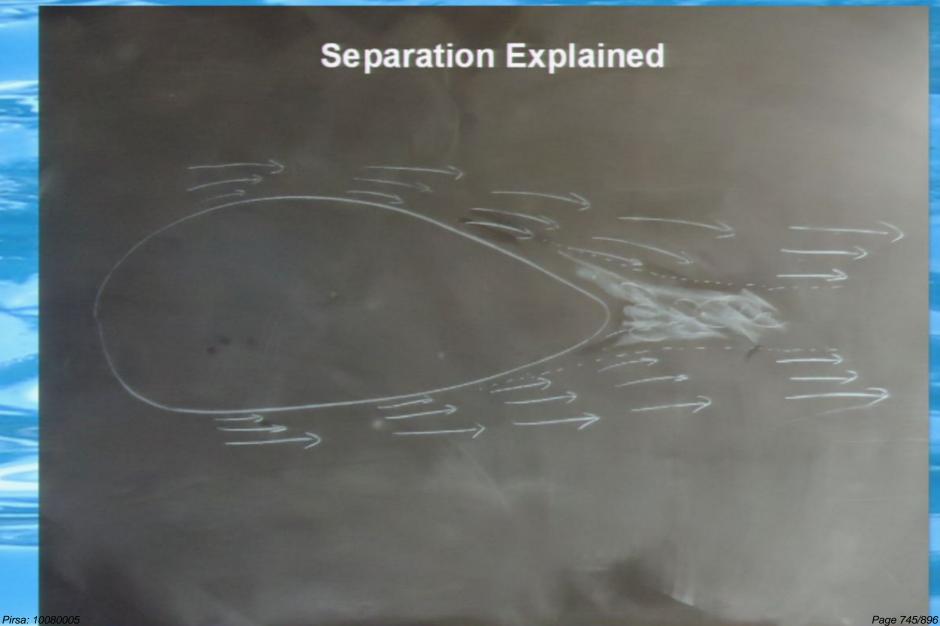
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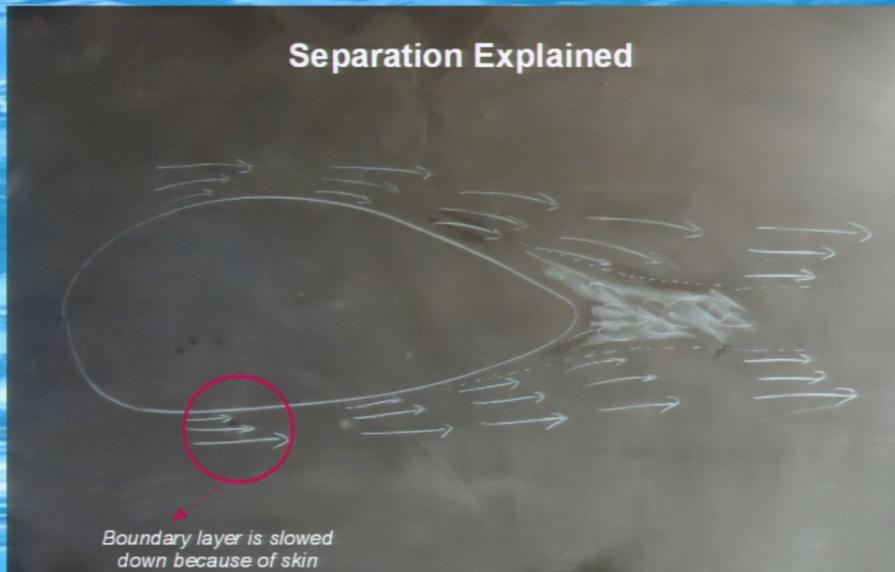
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Pirsa: 10080005 Page 744/896

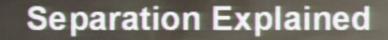




Pirsa: 10080005

friction...

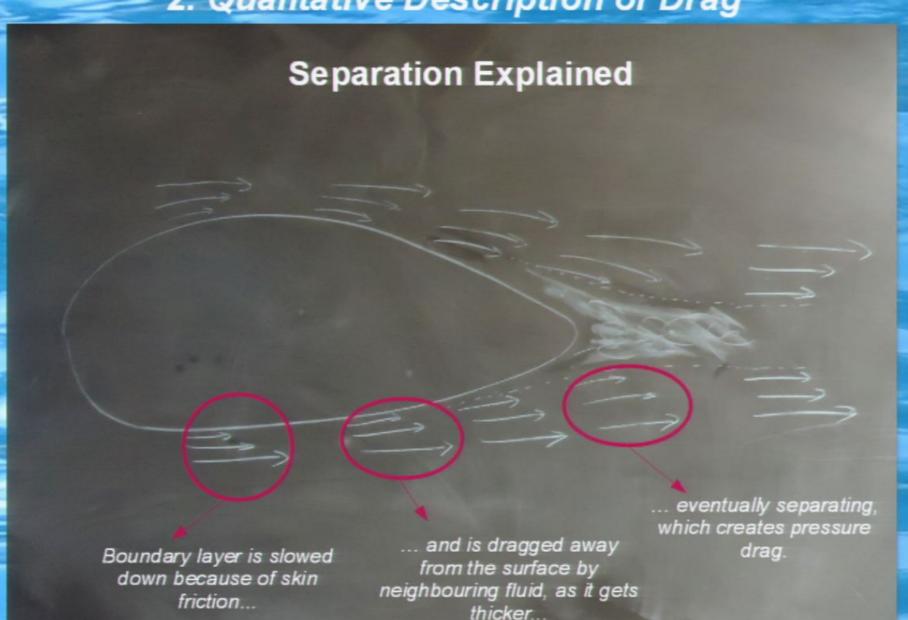
Page 746/896



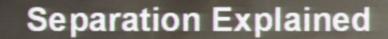
Boundary layer is slowed down because of skin friction...

... and is dragged away from the surface by neighbouring fluid, as it gets thicker...

Pirsa: 10080005



Pirsa: 10080005 Page 748/896



Wake (turbulence at very low viscosity)

Boundary layer is slowed down because of skin friction...

... and is dragged away from the surface by neighbouring fluid, as it gets thicker... ... eventually separating, which creates pressure drag.

While skin friction can only be reduced with skin surface smoothening body shape plays an important role in separation and pressure drag:

- minimizing the angle gradients in the surface leads to less separation;
- the less separation there is, the more pressure is recovered at the body's end, hence less pressure drag.

Streamlined body shapes seem to be more adequate for swimming than, say, squares or circles.

Open question – rigorous treatment!

Pirsa: 10080005 Page 750/896

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Pirsa: 10080005 Page 751/896

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Pirsa: 10080005 Page 752/896

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Pirsa: 10080005 Page 753/896

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Pirsa: 10080005

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Pirsa: 10080005 Page 755/896

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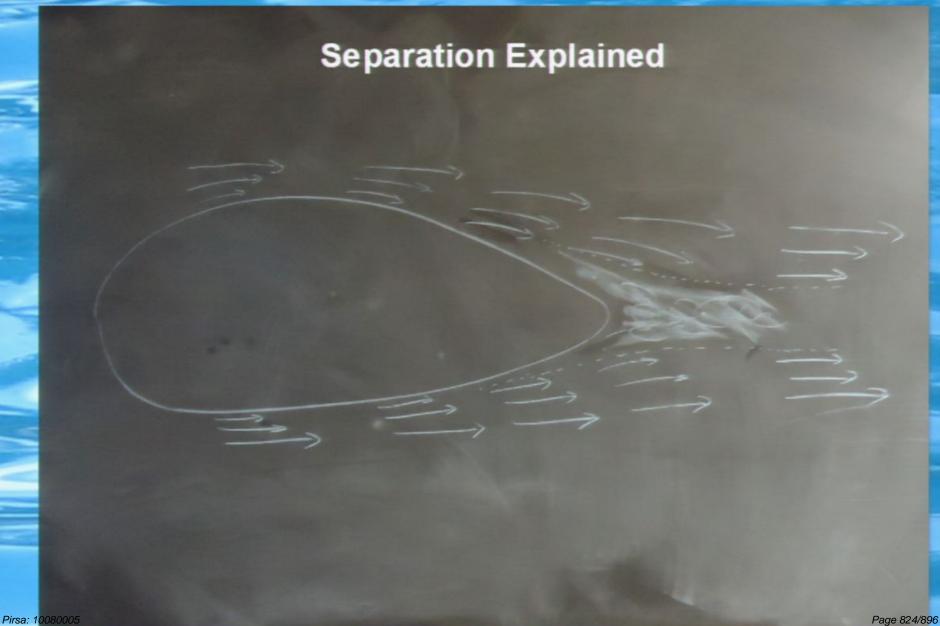
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2. Qualitative Description of Drag



1. Outline of the physical problem

 Consider the flow of a viscous fluid past an obstacle (equivalent to the swim of a body in a previously static fluid):

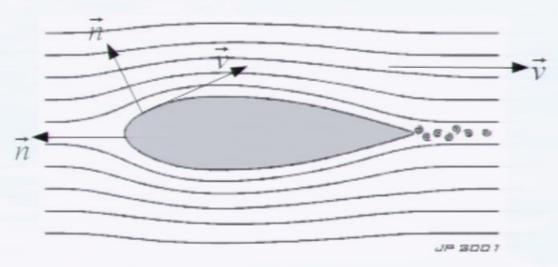


Image: Coilgun Systems website

- For simplicity, consider a 2D flow
- Velocity is constant far from the body, $\vec{v} = v \vec{e}_x$
- In the surface, the normal component of velocity vanishes, $\vec{v} \cdot \vec{n} = 0$

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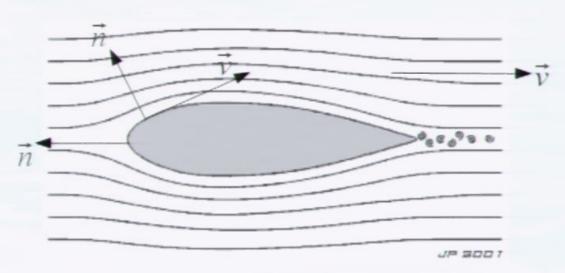


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The Ideal Body for Swimming (a Physics swan song) José Ricardo Oliveira Perimeter Scholars International 2010/11

 Streamlined body shapes are seen in most waterbound and flying animals; do they serve a purpose in swimming?

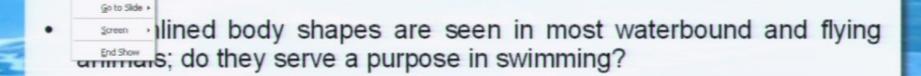


Image: flyfishingnature.com



Image 123rf.com

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Previous

Image: flyfishingnature.com



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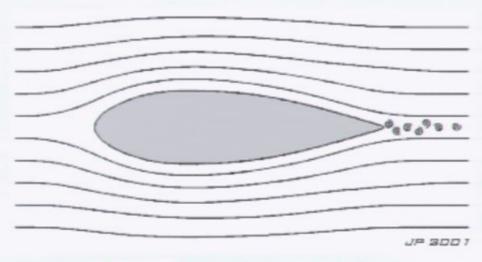


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 Clearly, if there is a point to the animals' body shapes, it is to reduce drag (as it slows you down, and requires a bigger effort to swim)

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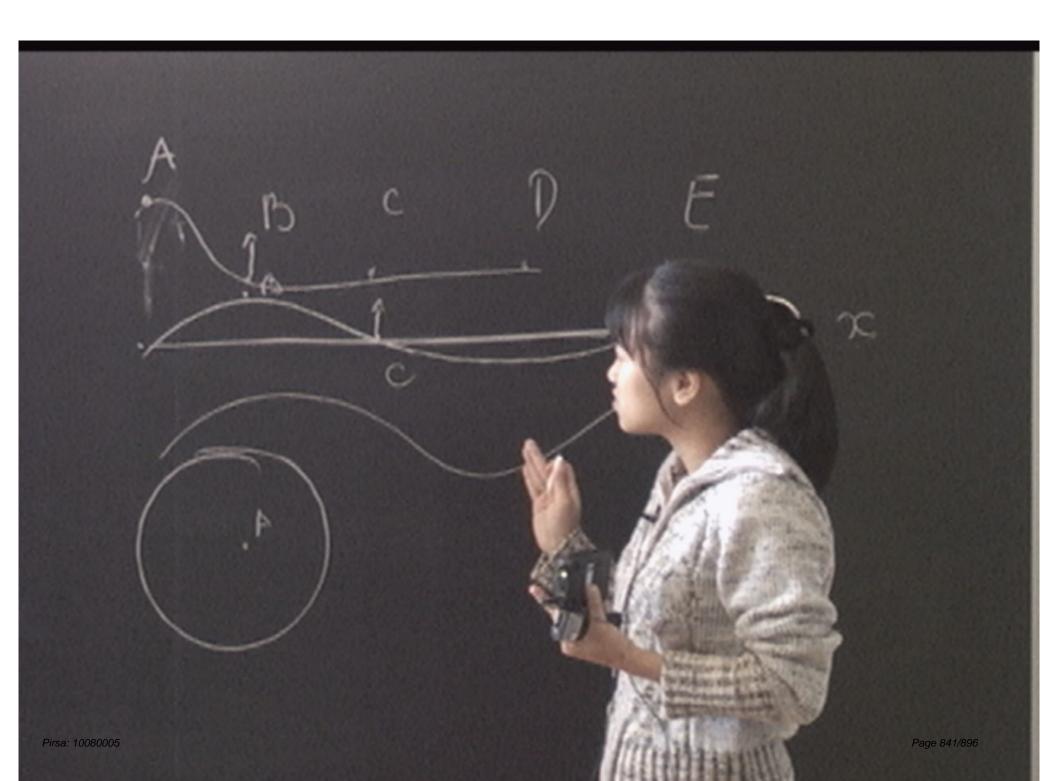


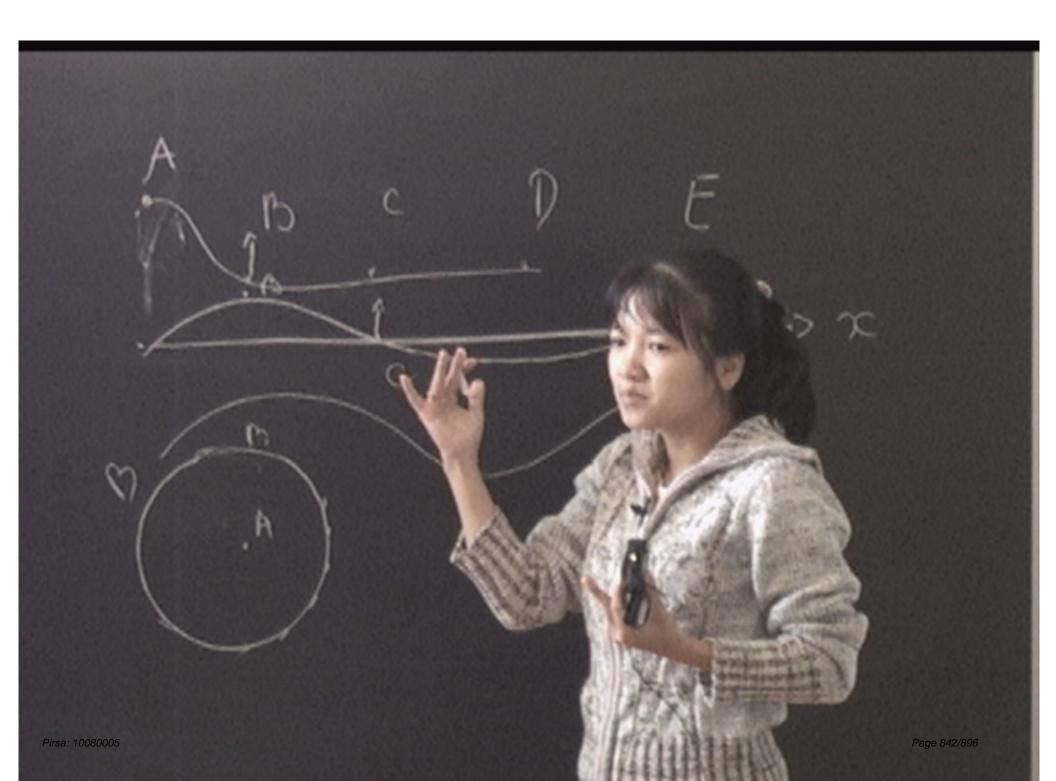


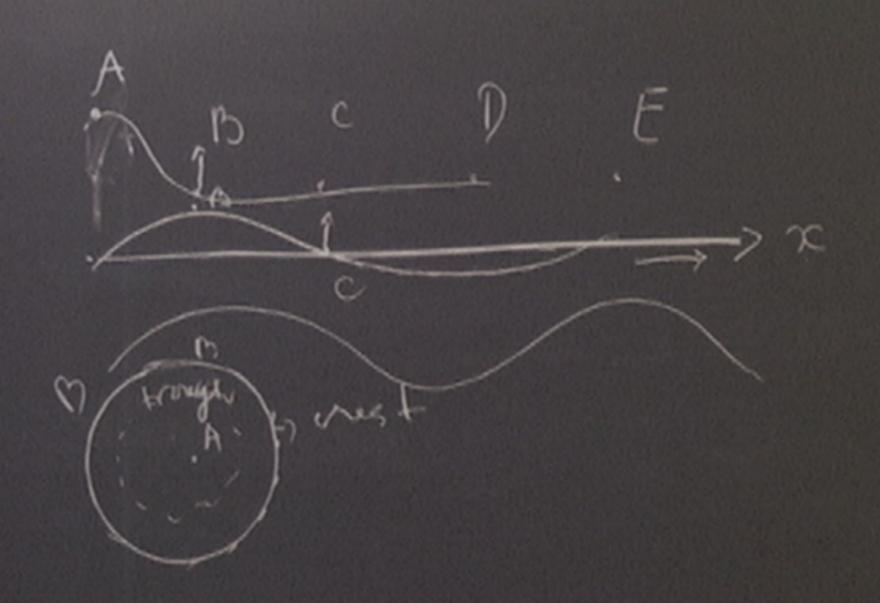




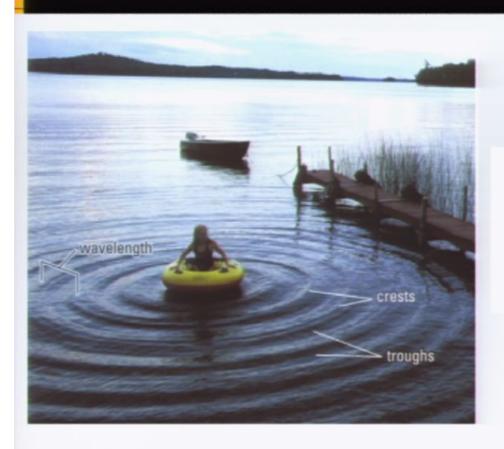


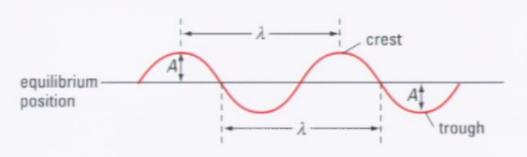




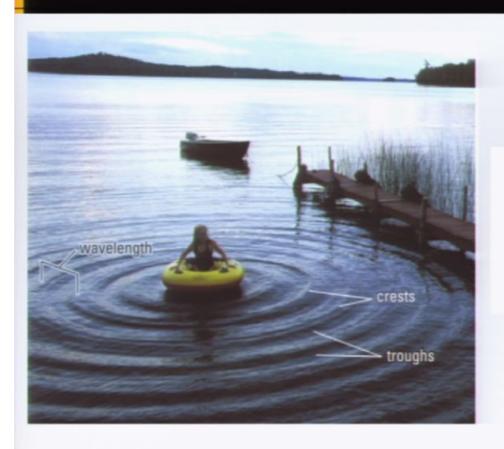


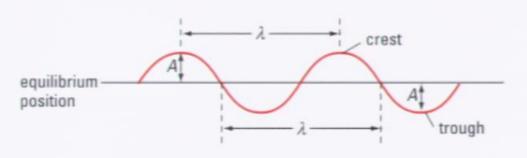
Propagation of vibration





Propagation of vibration





































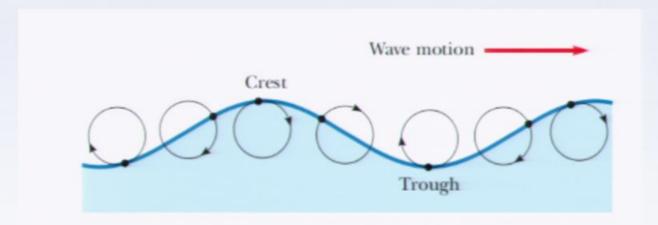


Contents

- Propagation of vibrations
- Types of wave

Is a water wave transverse or longitudinal?

Types of waves

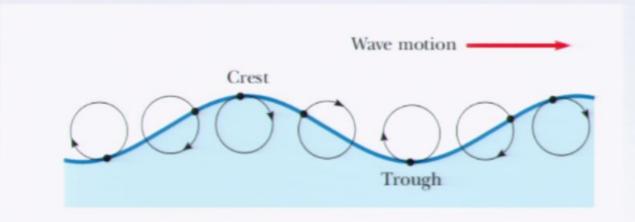


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Types of waves



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How Candles Burn



Trevor J. Rempel August 20, 2010



How Candles Burn



Trevor J. Rempel August 20, 2010



Outline

- Where Does the Wax Go?
- Capillary Action
 - Cohesion and Adhesion
 - Height of Liquid in a Tube
- Rest of the Story
- Conclusion



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Lighting the wick melts wax



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Lighting the wick melts wax



Candle burns until wax is gone

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Lighting the wick melts wax

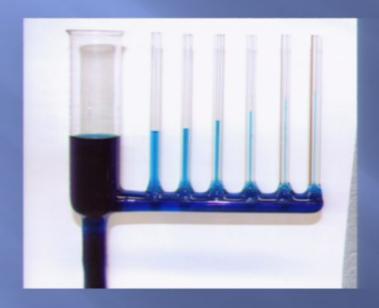


- Candle burns until wax is gone
- But where does the wax go?

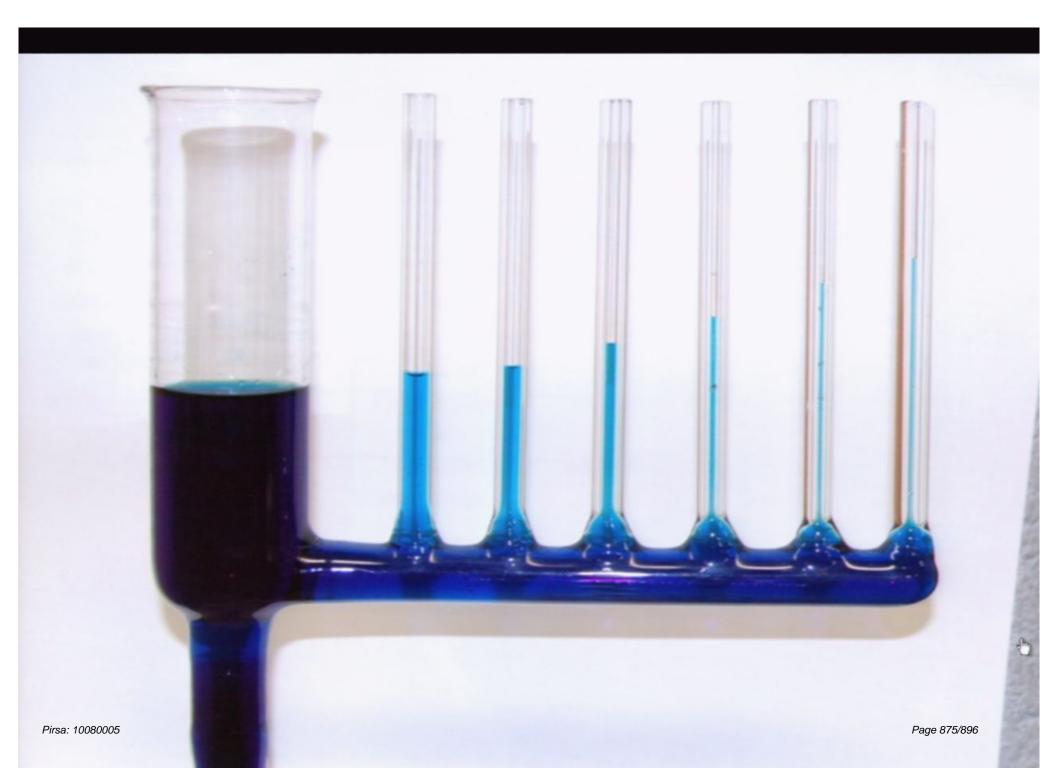
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Capillary Action

Tendency of liquids to rise against gravity

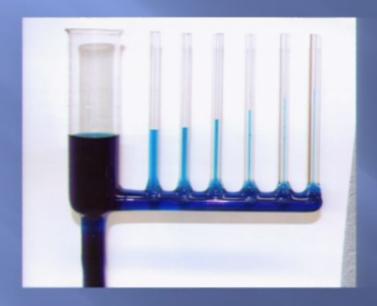


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Capillary Action

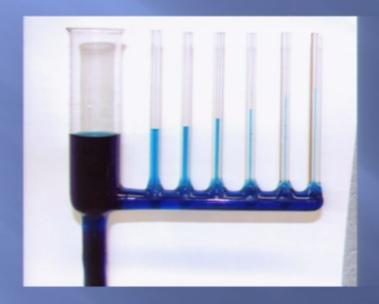
Tendency of liquids to rise against gravity



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Capillary Action

Tendency of liquids to rise against gravity



- Common phenomenon
 - Paper Towels

Pirsa: 10080005 Sponges

Cohesive Force

Intermolecular forces between like molecules

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Cohesive Force

- Intermolecular forces between like molecules
- Cause of Surface Tension





Cohesive Force

- Intermolecular forces between like molecules
- Cause of Surface Tension



Adhesive Force

Intermolecular forces between unlike molecules

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Adhesive Force

- Intermolecular forces between unlike molecules
- Why you need to dry your dishes



Adhesive Force

- Intermolecular forces between unlike molecules
- Why you need to dry your dishes

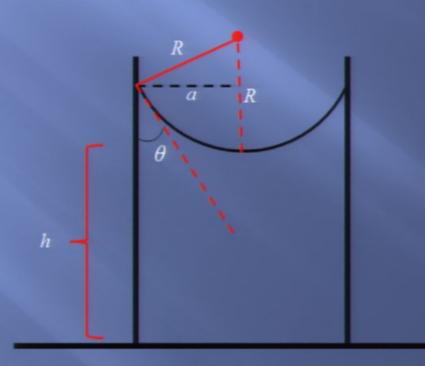




Consider a small tube immersed in liquid



Interplay between cohesive and adhesive forces

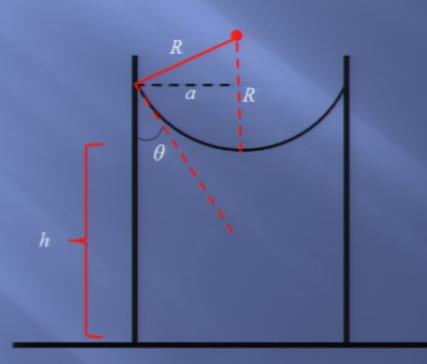


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Consider a small tube immersed in liquid



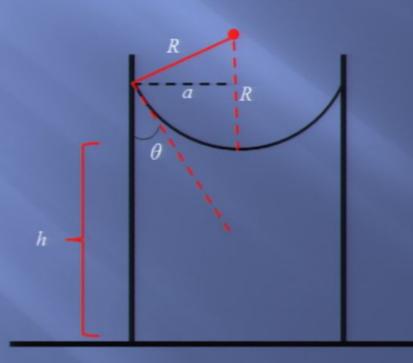
Interplay between cohesive and adhesive forces



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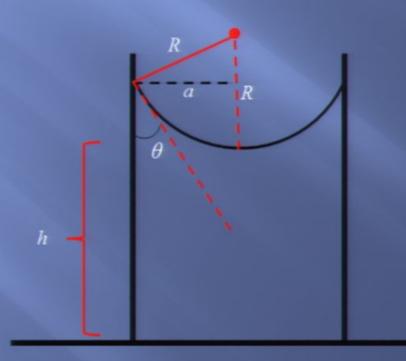
$$\Delta \mathfrak{P} = \frac{2 \mathfrak{P} \mathfrak{P}}{\mathfrak{P}}$$

$$\Delta M = M h$$

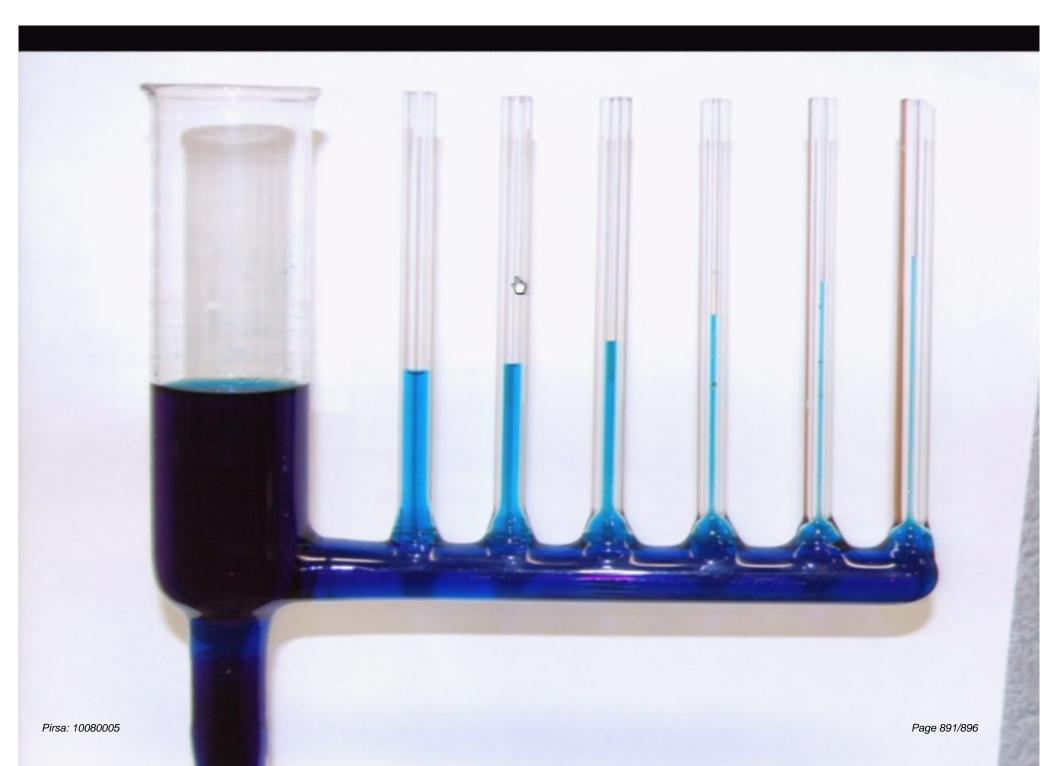


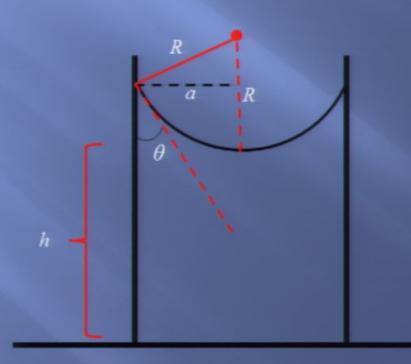
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$$h = \frac{2 \, \text{CRRTRRRRP}}{2 \, \text{RRRP}}$$



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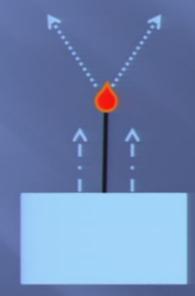
Rest of the Story

 Once wax is melted, capillary action draws wax up the wick



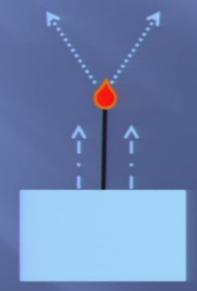
Rest of the Story

- Once wax is melted, capillary action draws wax up the wick
- Heat from flame then evaporates the wax



Rest of the Story

- Once wax is melted, capillary action draws wax up the wick
- Heat from flame then evaporates the wax
- Process continues until wax runs out



Conclusion

- Candle relies on capillary action
- After initially melting wax, adhesive forces between wax and wick draw wax up wick
- Heat from flame then evaporates the wax

