

# Horizontes para ondas superficiais em fluidos

Alberto Saa



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Alberto Saa

J.C. Sartorelli  
E. Constantino



M. Richartz  
C. Chirenti



# Buracos negros acústicos



The  
Economist

**Black holes on a desktop**

**Dumb insolence**

Sound may offer a better way than light to test Stephen Hawking's prediction that black holes emit radiation

# Buracos negros acústicos

- Introdução/motivação
- Fundamentos hidrodinâmicos
- Horizontes para ondas superficiais

# Relatividade Geral

- Teoria de Gravitação

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- Equações de Einstein

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- Equações de Einstein

$$R_{ab} - \frac{1}{2}g_{ab}R = \frac{8\pi C}{c^4}T_{ab}$$

# Relatividade Geral

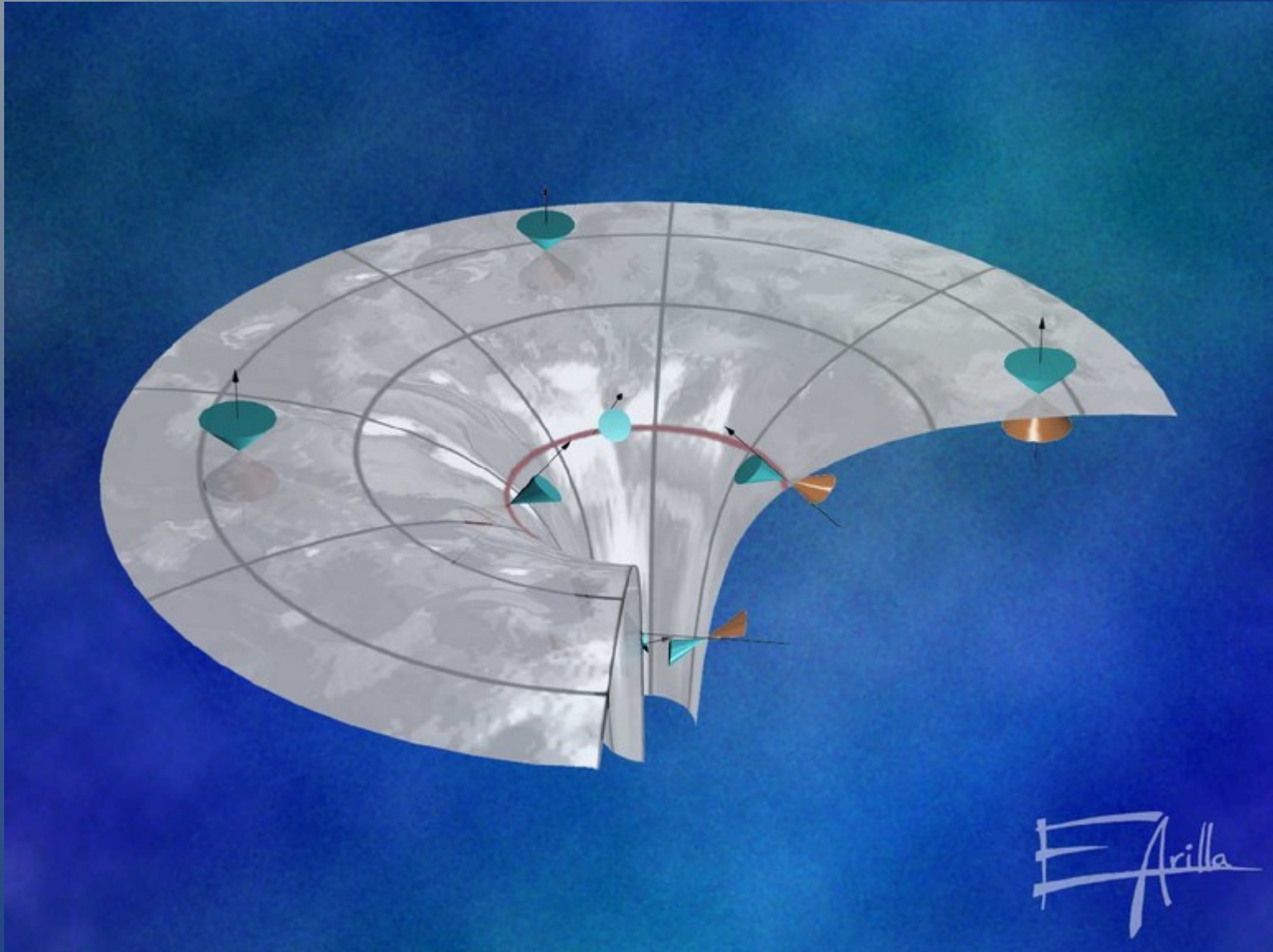
- Teoria de Gravitação
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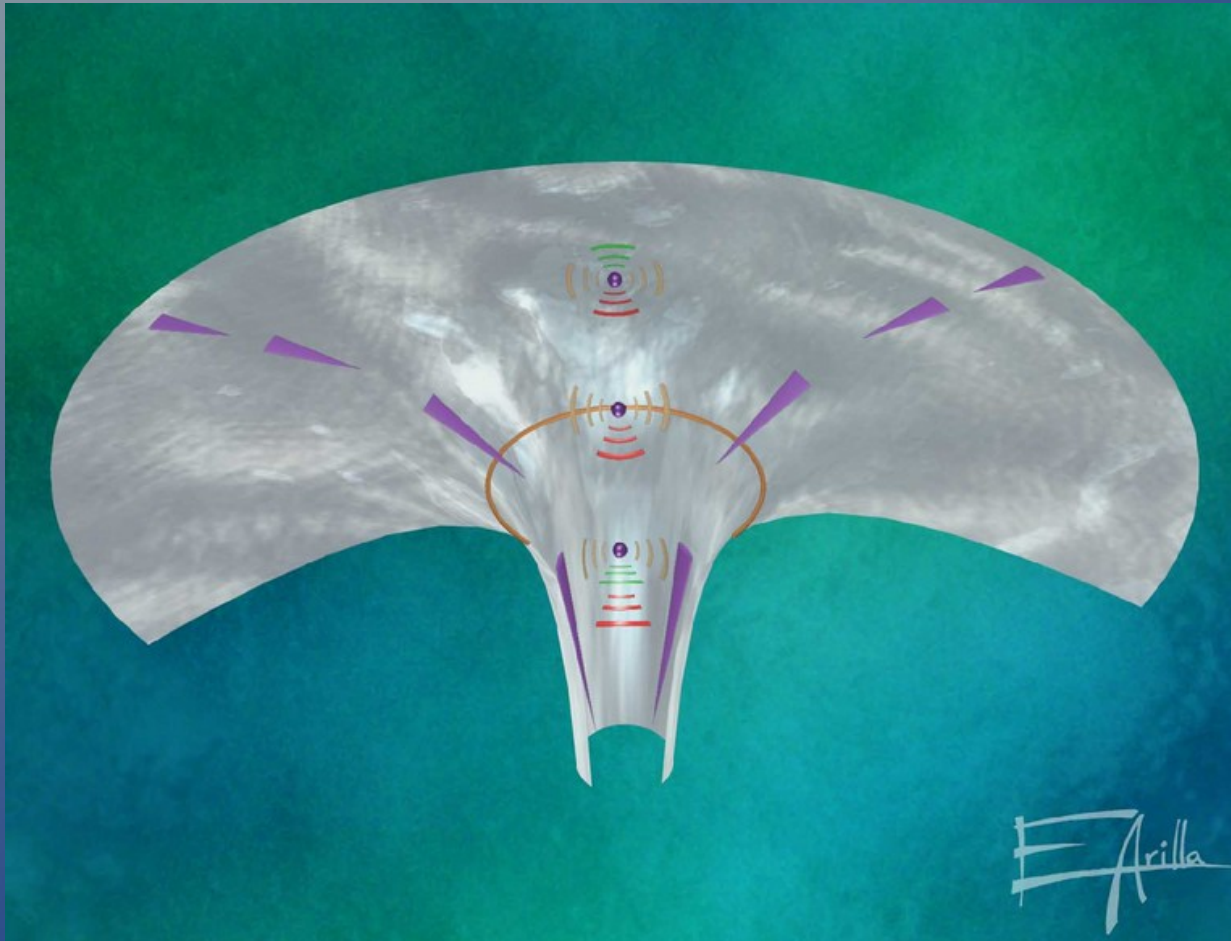
- Soluções: Buracos Negros



# Buracos Negros



# Horizonte de Eventos



LIVING  REVIEWS  
*in relativity*

Vol. 14 (2011) > Irr-2011-3

*Living Rev. Relativity* 14 (2011), 3

**Analogue Gravity**

Carlos Barceló and Stefano Liberati and Matt Visser

# Solução de Schwarzschild

$$ds^2 = - \left( 1 - \frac{2M}{r} \right) dt^2 + \frac{dr^2}{1 - \frac{2M}{r}} + r^2 d\Omega^2$$

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$r = 2M \rightarrow$  Horizonte de eventos

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Solução de Schwarzschild é estacionária, mas não estática!

# Teoria de Campos sobre Espaços Curvos

- Campos escalares

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$$\Delta\phi \equiv \frac{1}{\sqrt{-g}} \partial_\mu (\sqrt{-g} g^{\mu\nu} \partial_\nu \phi) = 0.$$

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- Criação de partículas



# Erwin Schrödinger - 1939

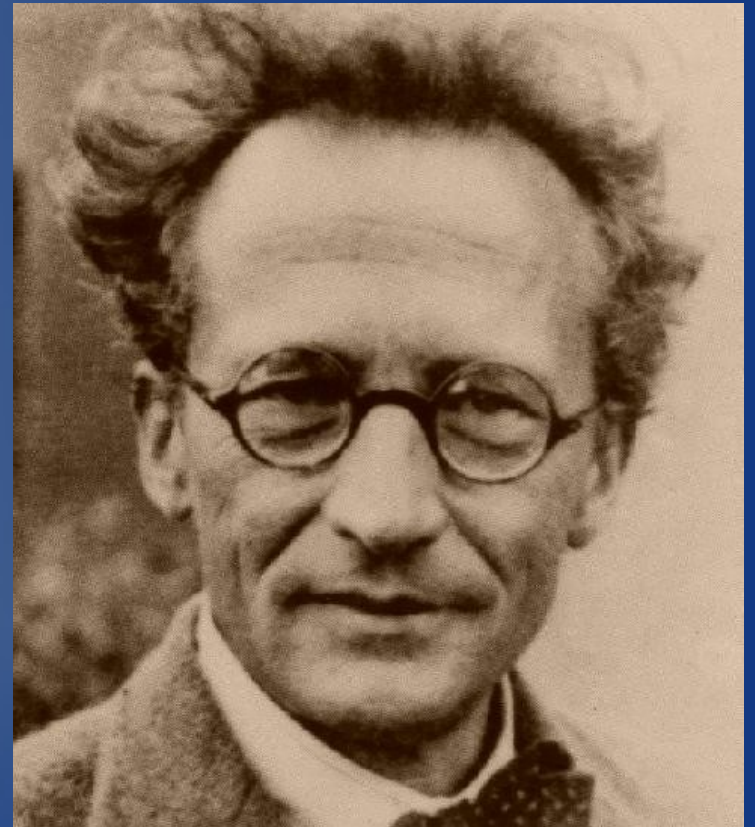
Physica VI, no 9

October 1939

## THE PROPER VIBRATIONS OF THE EXPANDING UNIVERSE

by ERWIN SCHRÖDINGER

§ 1. *Introduction and summary.* Wave mechanics imposes an a priori reason for assuming space to be closed; for then and only then are its proper modes discontinuous and provide an adequate description of the observed atomicity of matter and light. — Einstein's theory of gravitation imposes an a priori reason for assuming space to be, if closed, expanding or contracting; for this theory does not admit of a stable static solution. — The observed facts are, to say the least, not contrary to these assumptions.



# Erwin Schrödinger - 1939

Physica VI, no 9

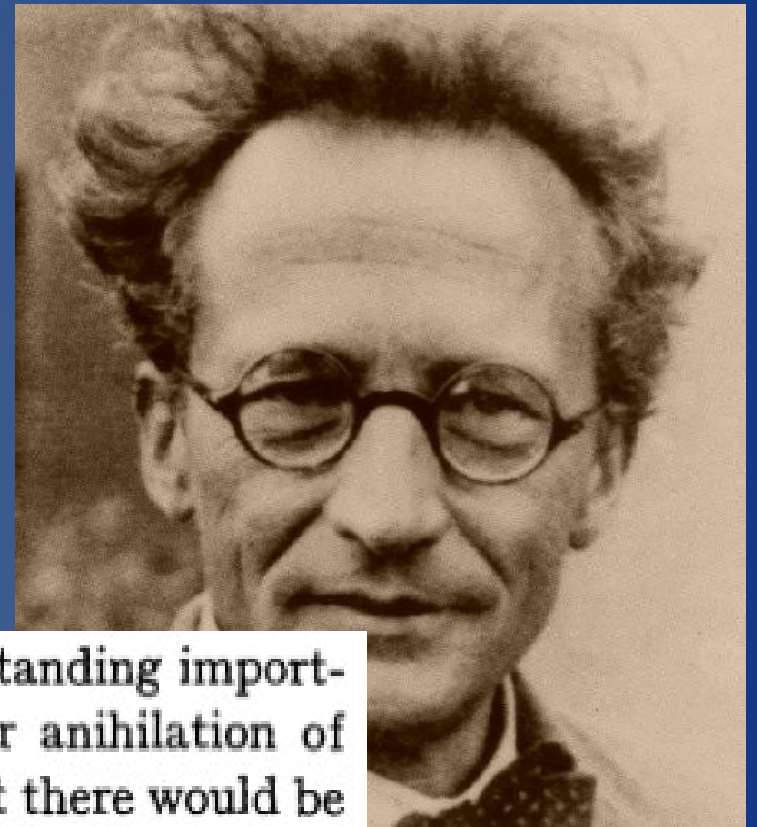
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Generally speaking this is a phenomenon of outstanding importance. With particles it would mean production or annihilation of matter, merely by the expansion, whereas with light there would be a production of light travelling in the opposite direction, thus a sort of reflexion of light in homogeneous space. Alarmed by these prospects, I have investigated the question in more detail. Fortunately

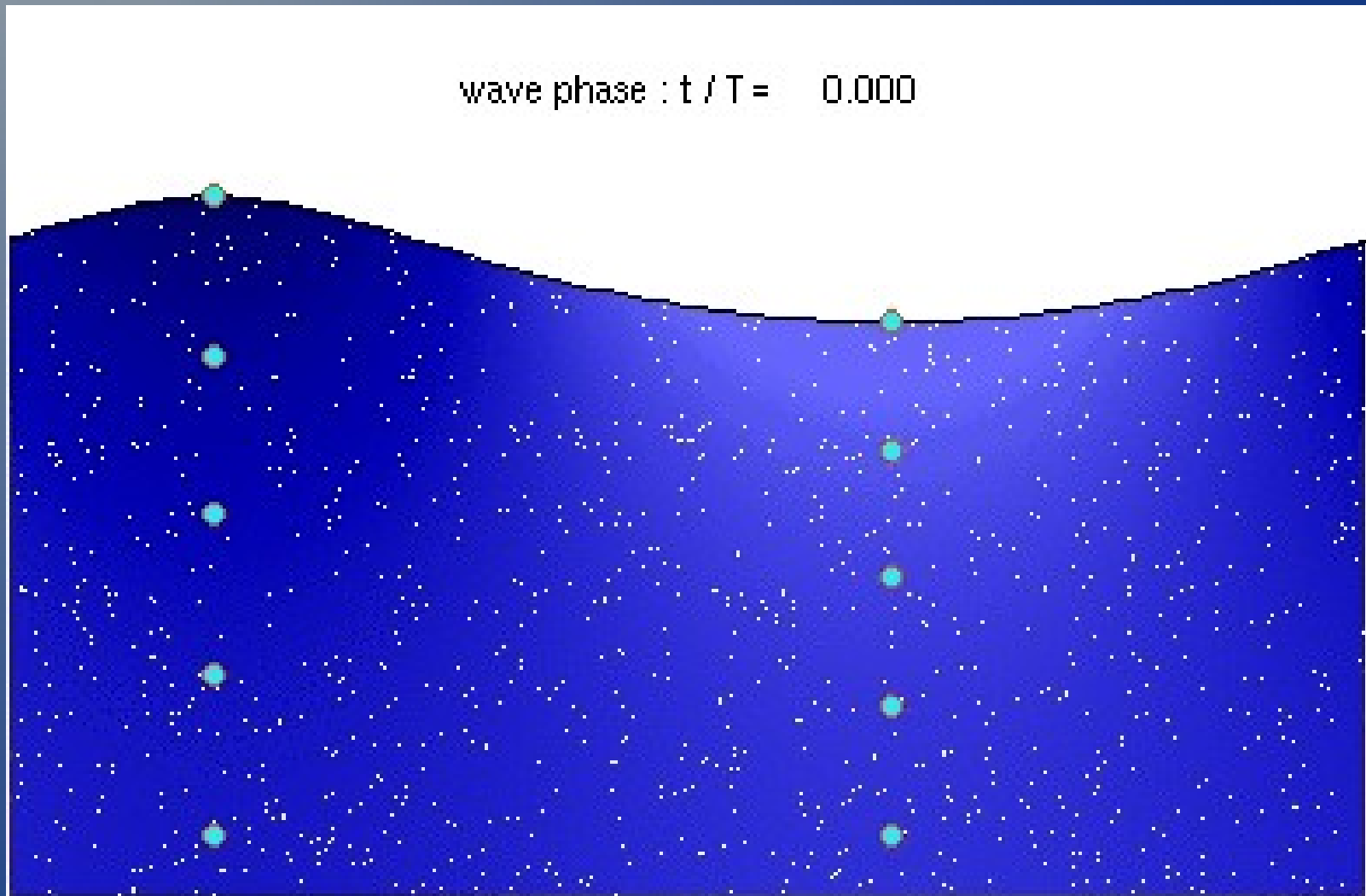


# Análogo hidrodinâmico



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# Ondas de (gravidade) em superfícies



# Perturbações hidrodinâmicas

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$$\Delta\phi \equiv \frac{1}{\sqrt{-g}} \partial_\mu \left( \sqrt{-g} g^{\mu\nu} \partial_\nu \phi \right) = 0.$$

$$g_{\mu\nu}(t, \mathbf{x}) \equiv \frac{\rho}{c} \begin{bmatrix} -(c^2 - v^2) & \vdots & -\mathbf{v}^T \\ \dots & \dots & \dots \\ -\mathbf{v} & \vdots & \mathbf{I} \end{bmatrix}$$



# Ondas de (gravidade) em superfícies

REVISTA BRASILEIRA DE  
ENSINO DE FÍSICA

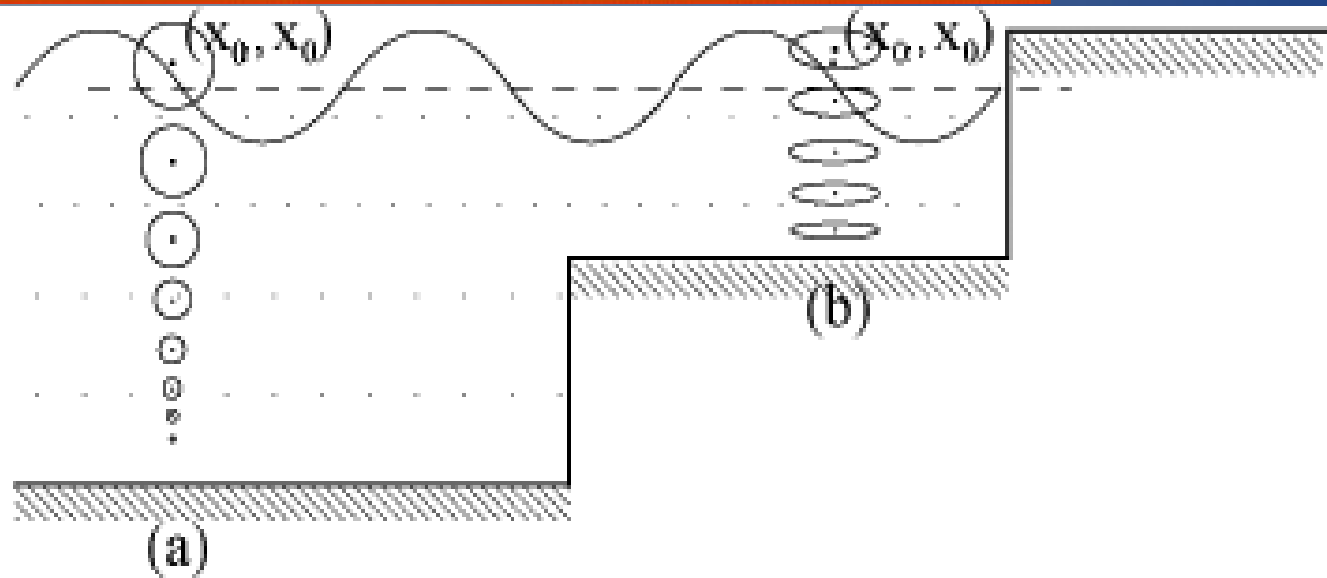


Figura 4 - Trajetórias das partículas em (a) águas profundas e (b) rasas.

**Ondas superficiais de gravidade** *Rev. Bras. Ensino Fís.* vol.31 no.2 São Paulo Abr./June 2009

Alcione S. Fernandes<sup>1</sup>; Giselle M. Alves

Departamento de Física, Universidade Federal do Paraná, Curitiba, PR, Brasil Escola  
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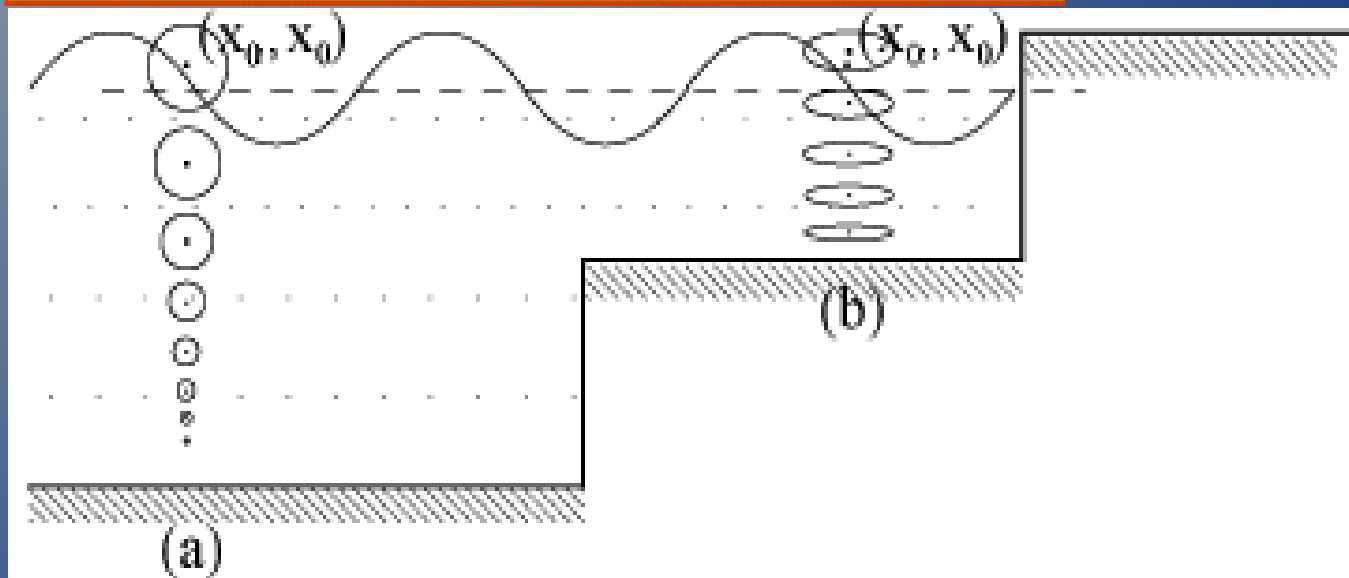


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$$c(\lambda) = \sqrt{\frac{g\lambda}{2\pi}}$$

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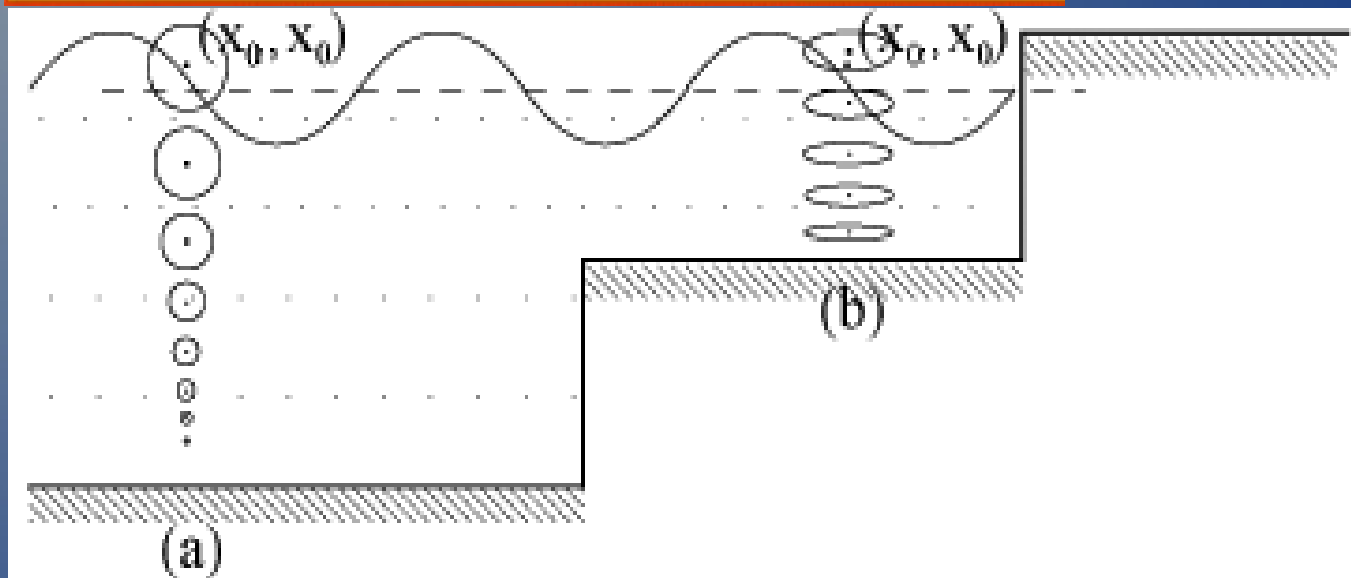
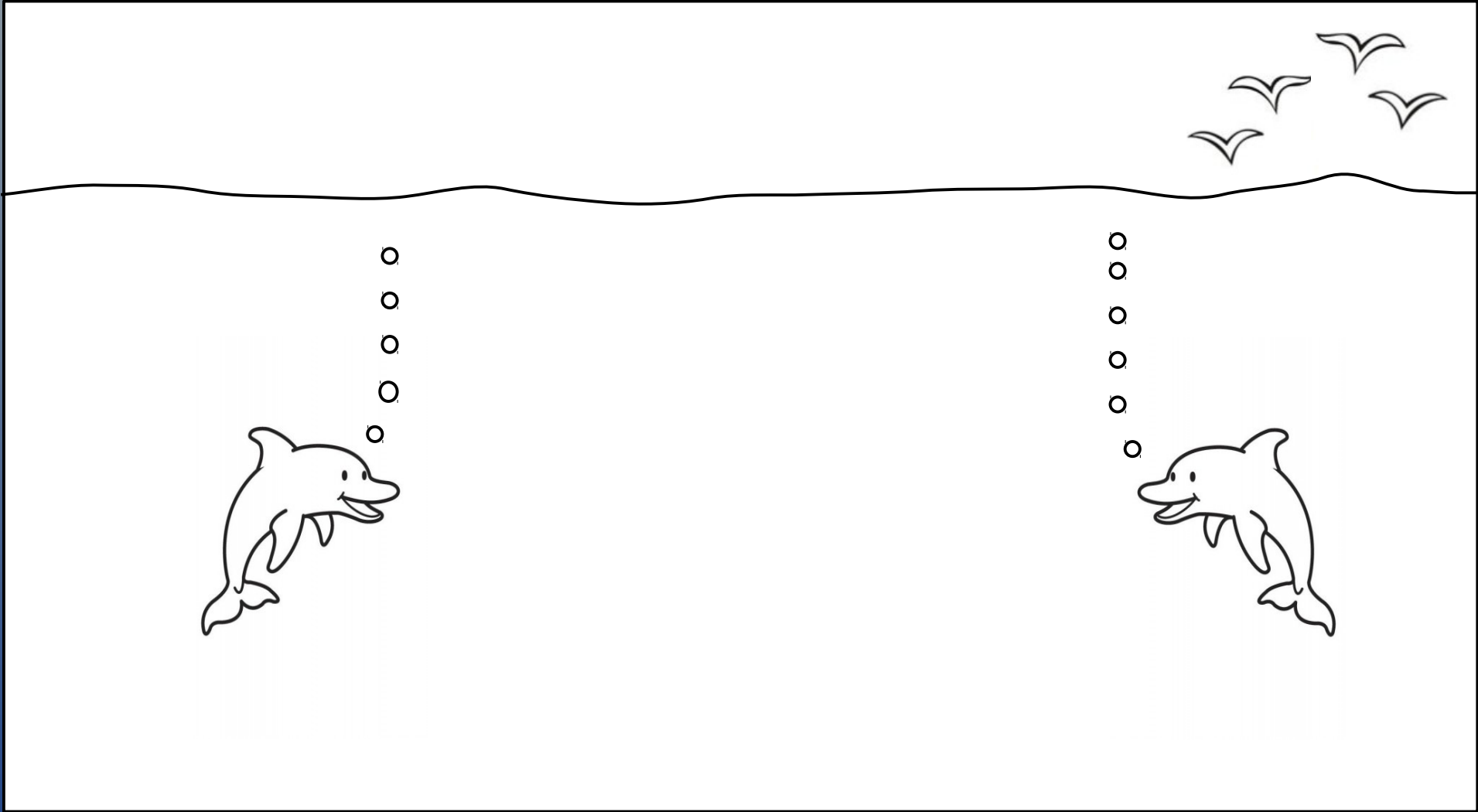
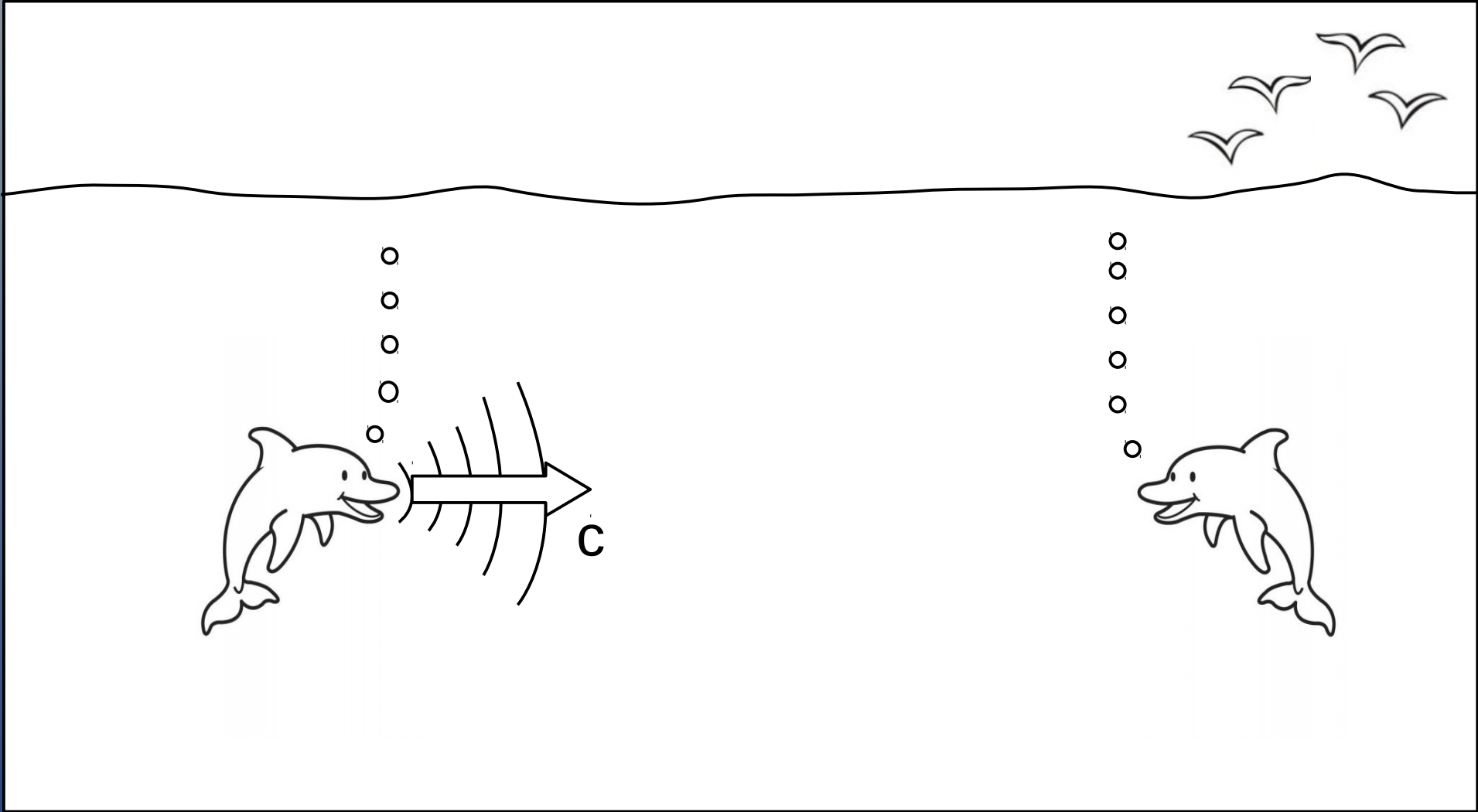
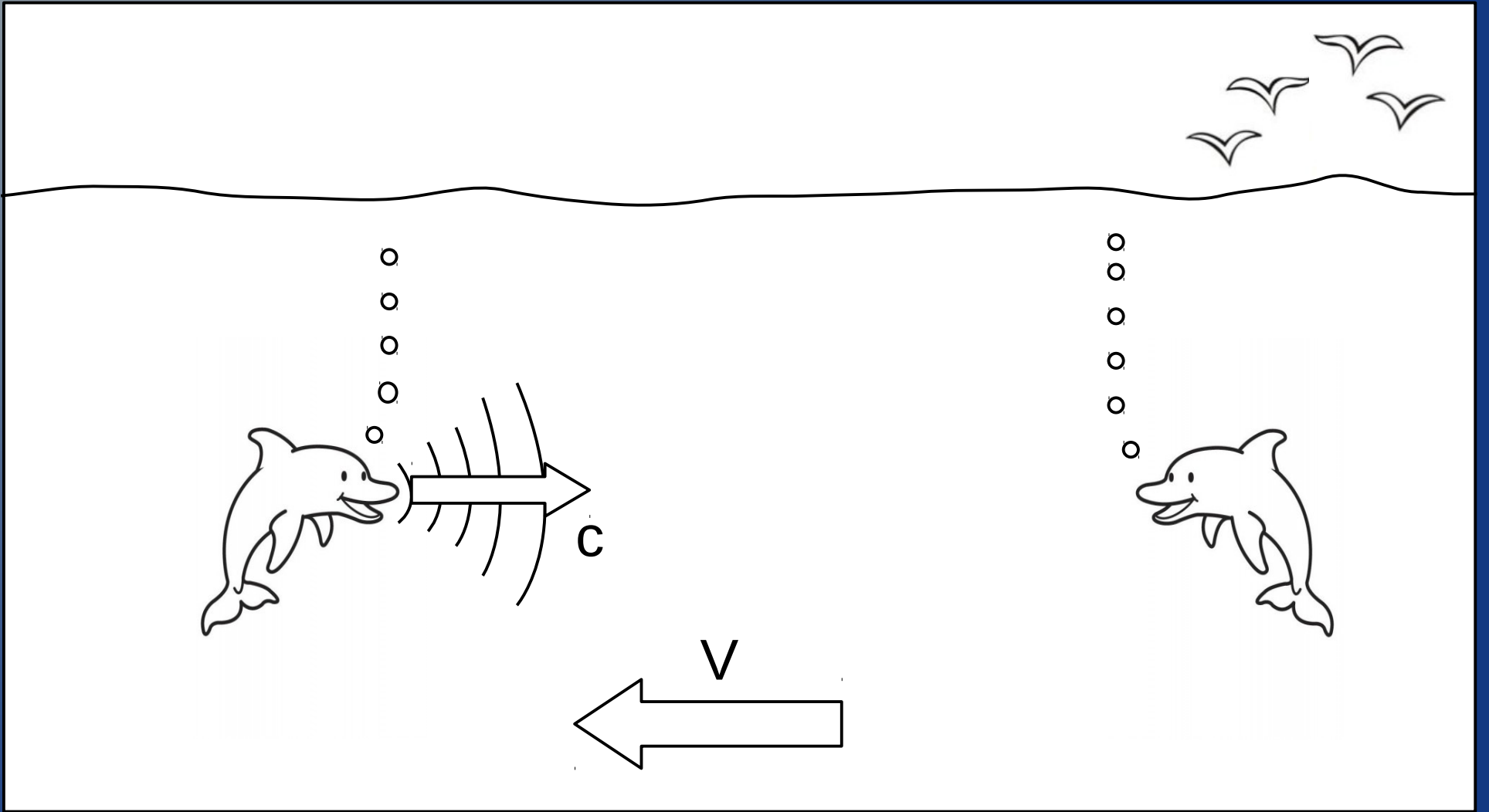


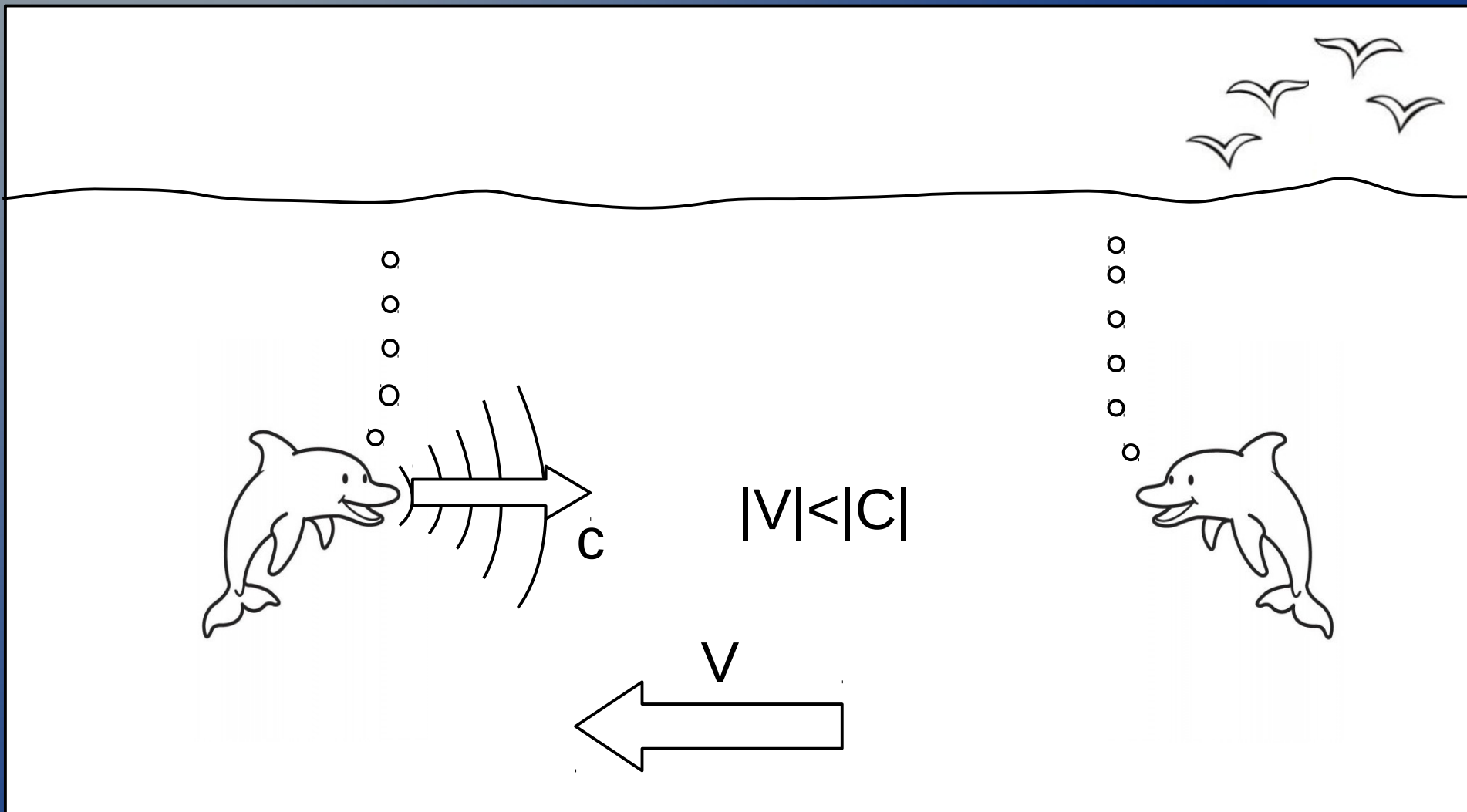
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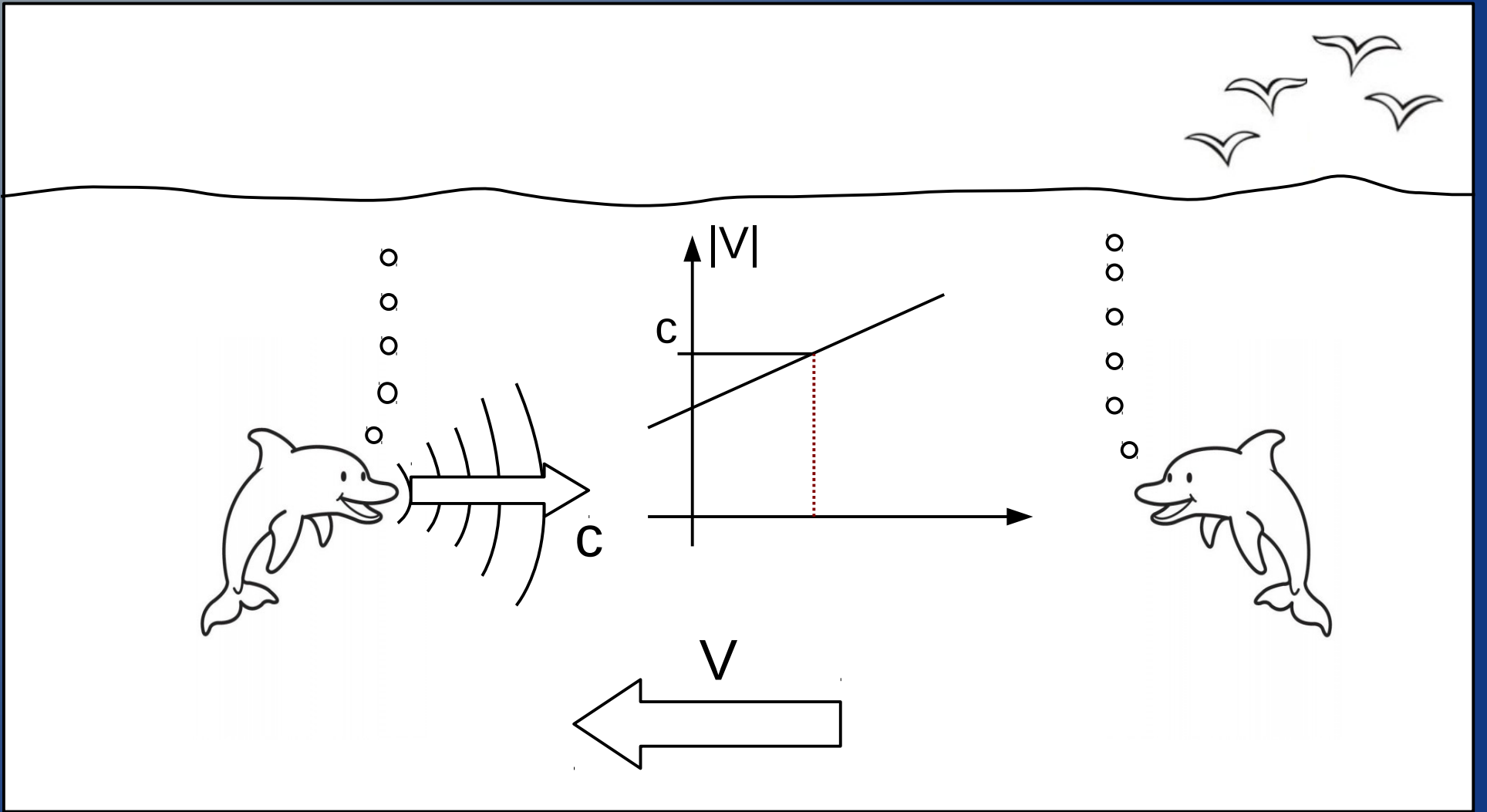
$$c(\lambda) = \sqrt{\frac{g\lambda}{2\pi}} \quad c = \sqrt{gh}$$

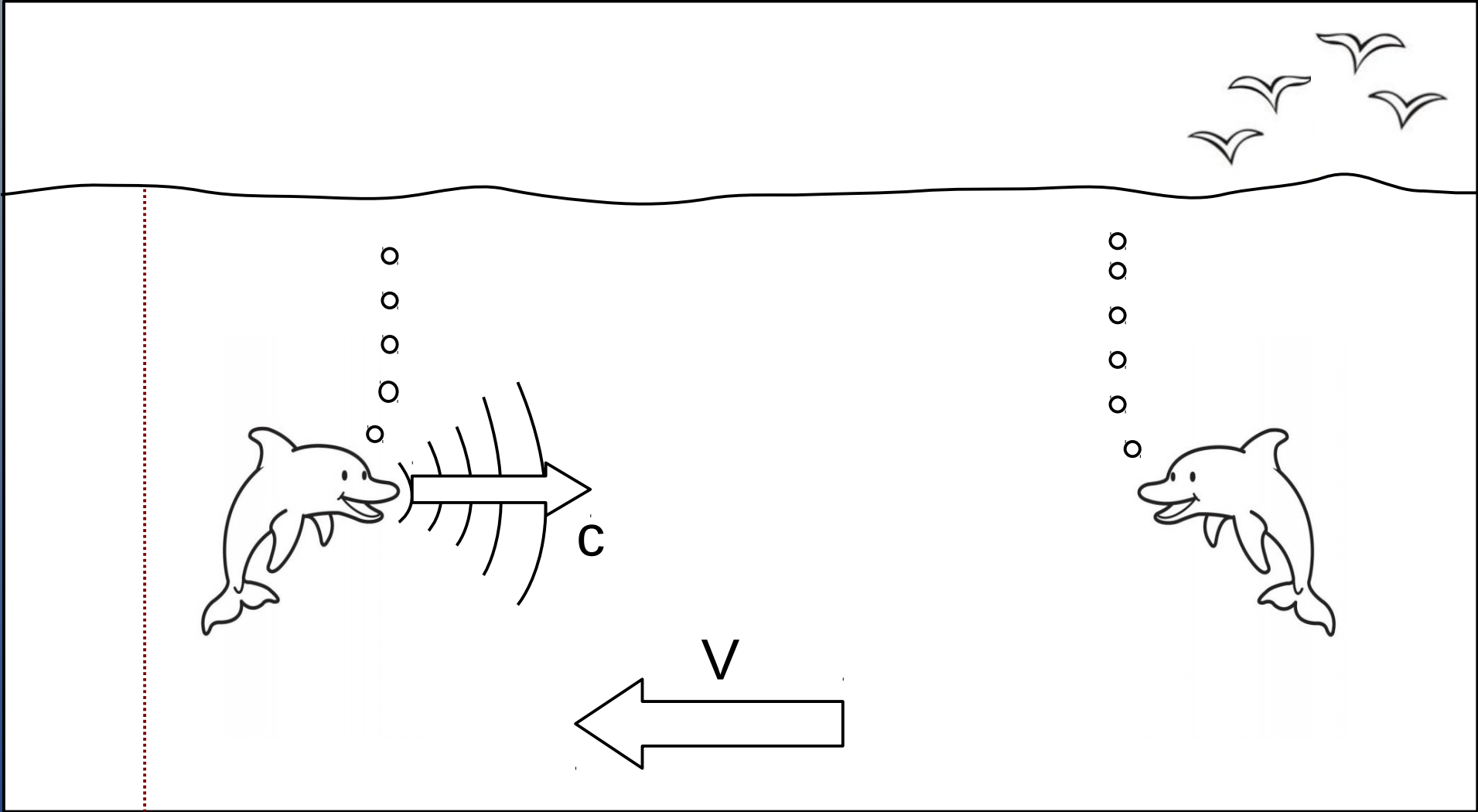




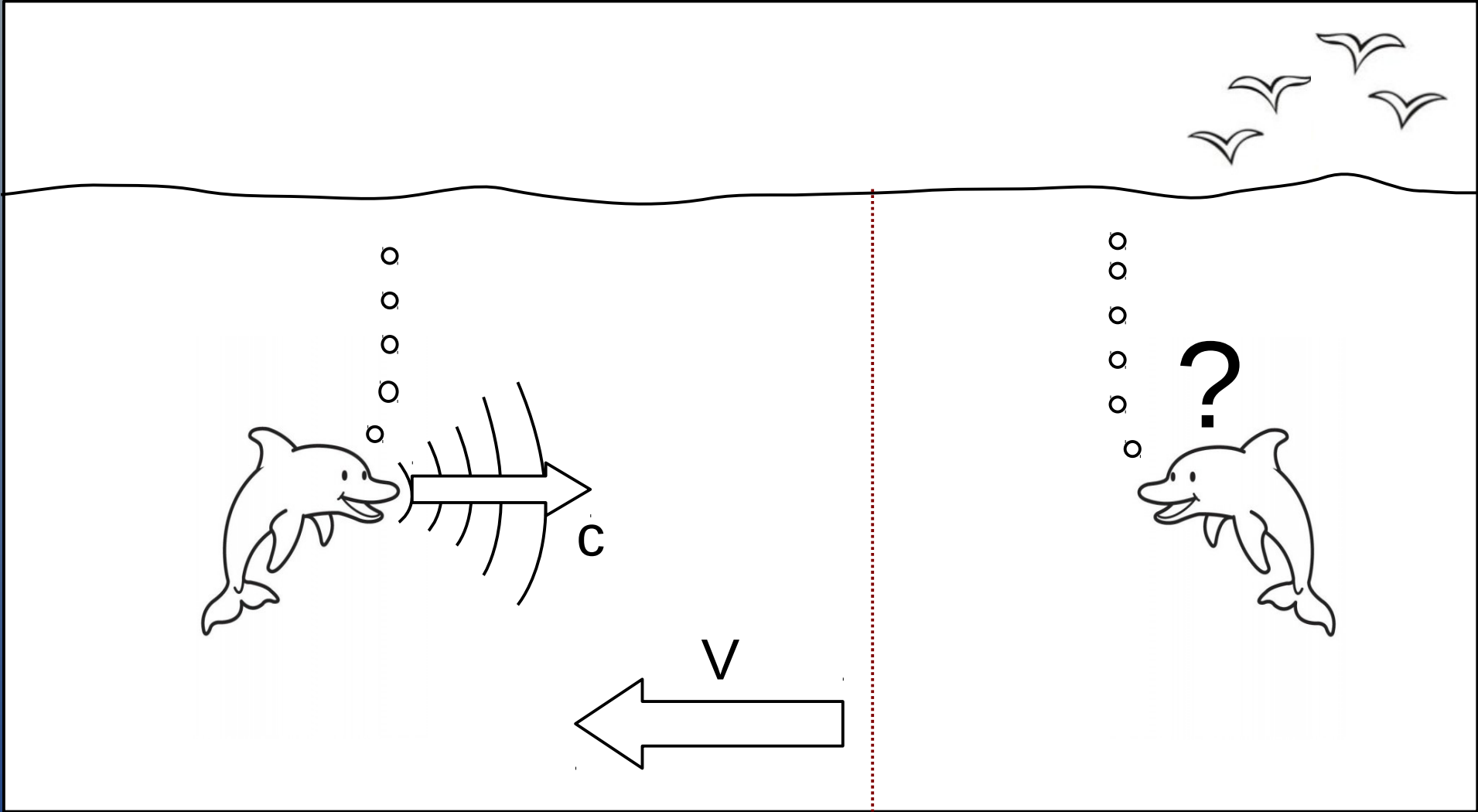












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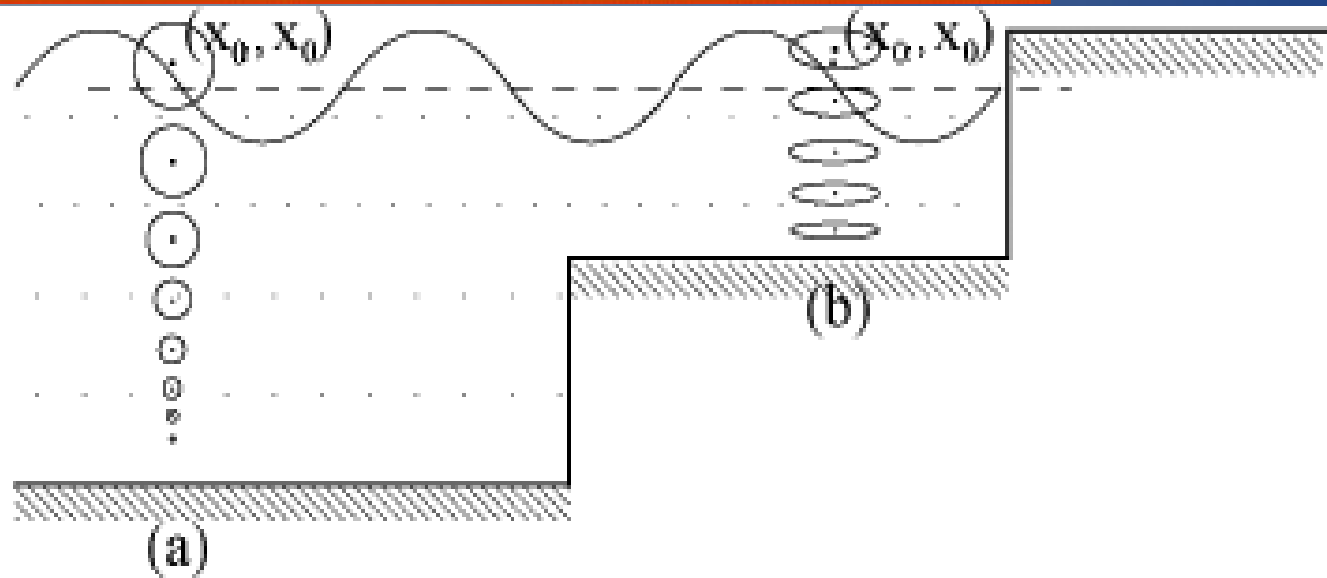


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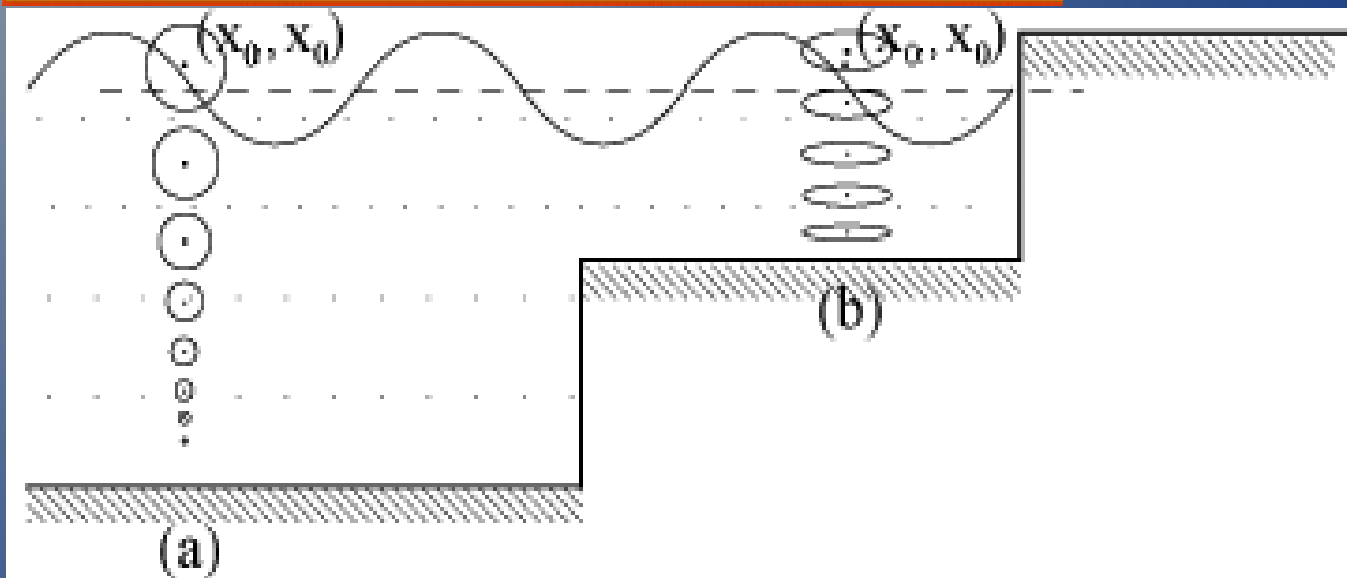


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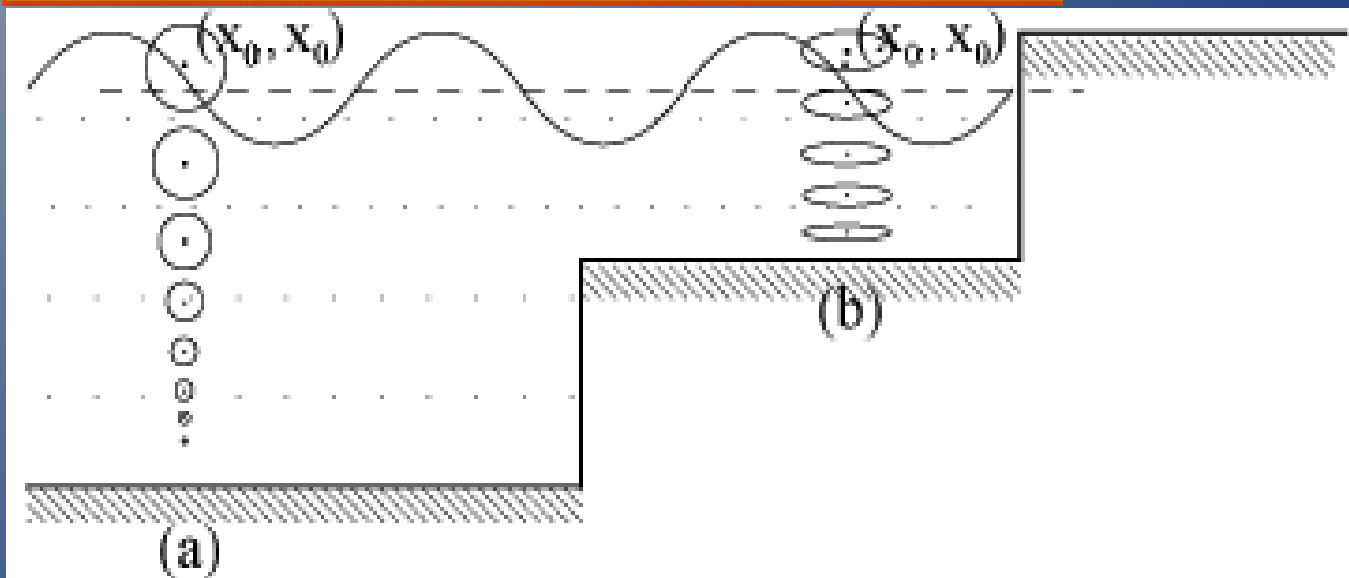
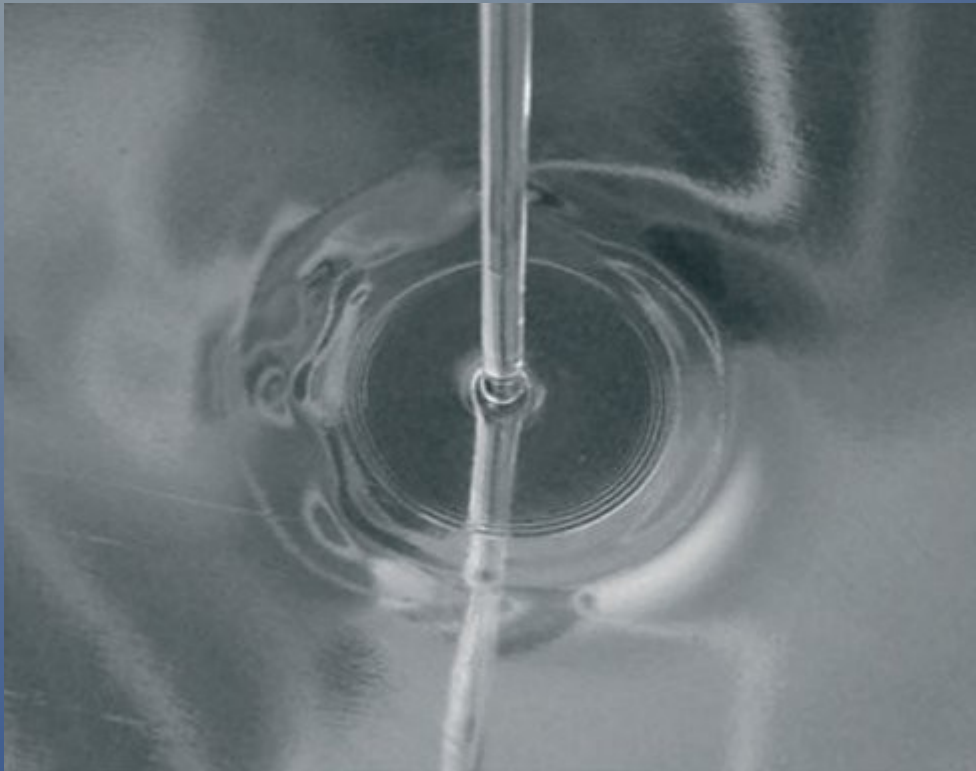


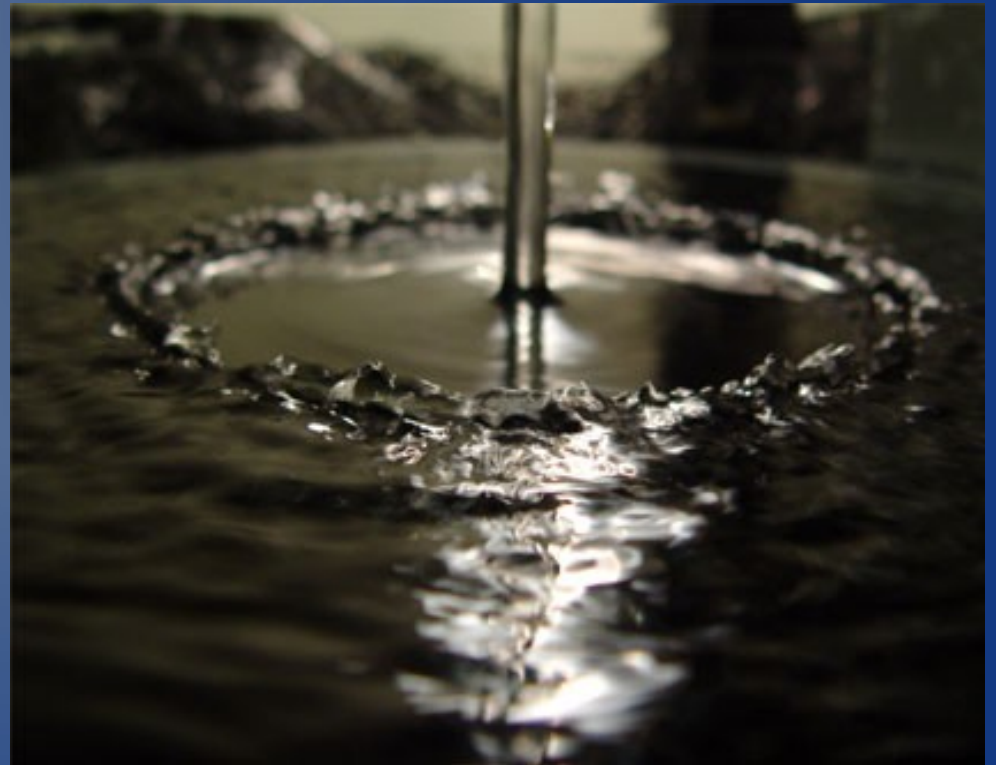
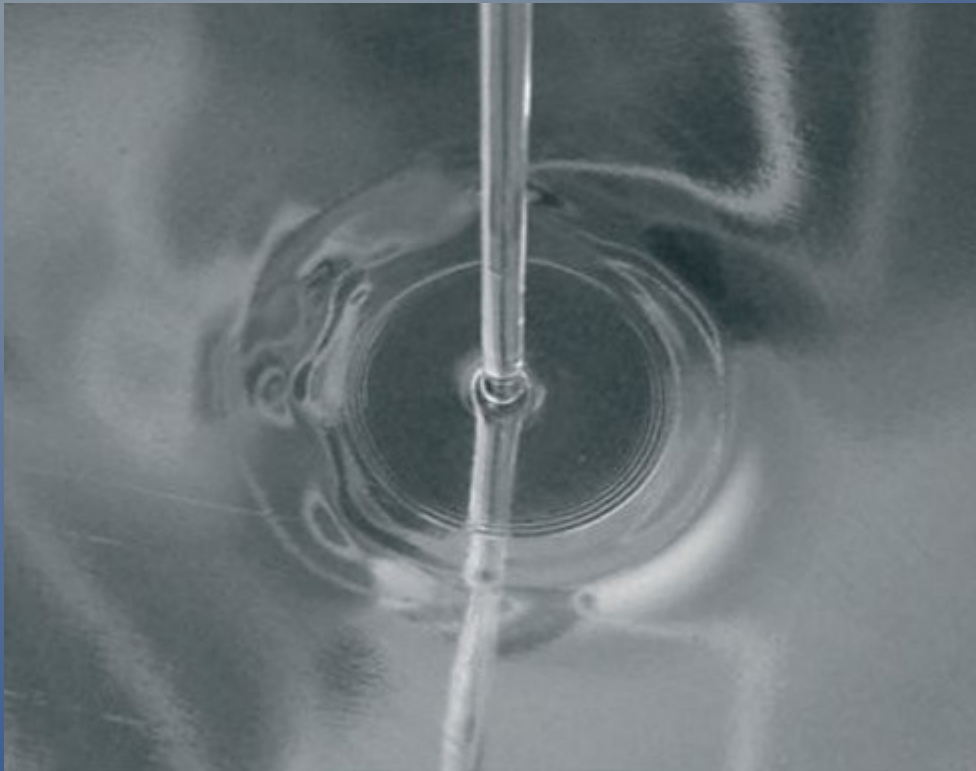
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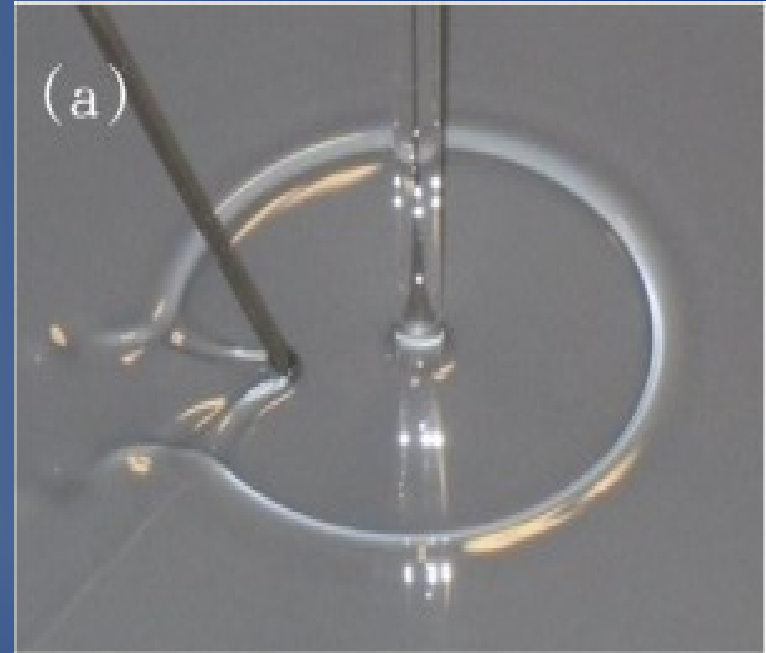


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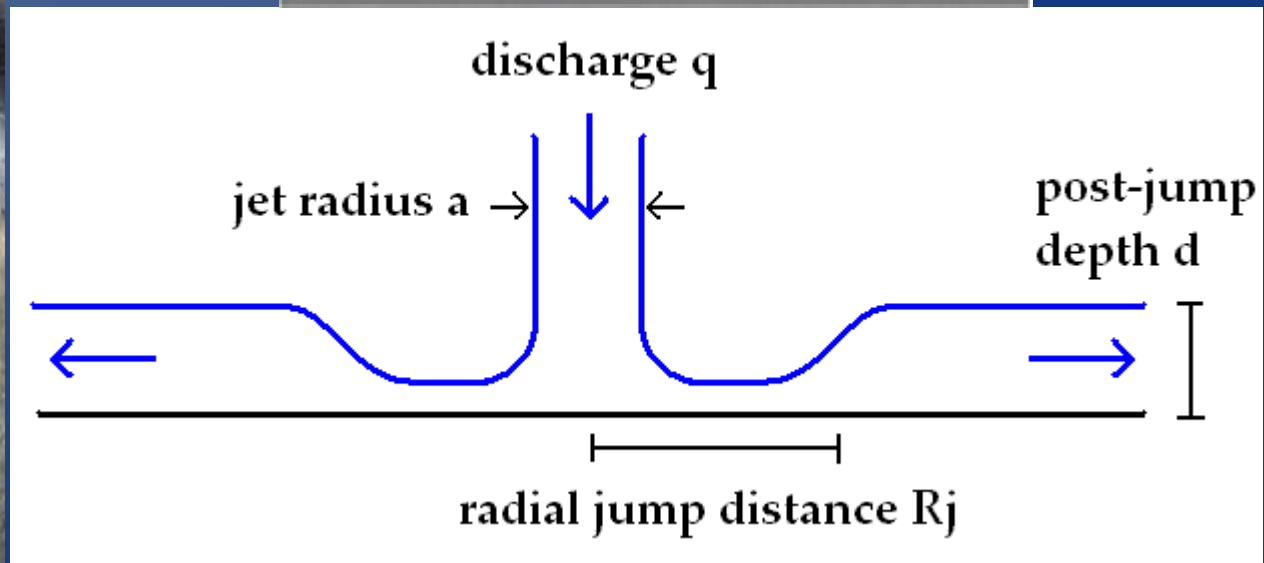
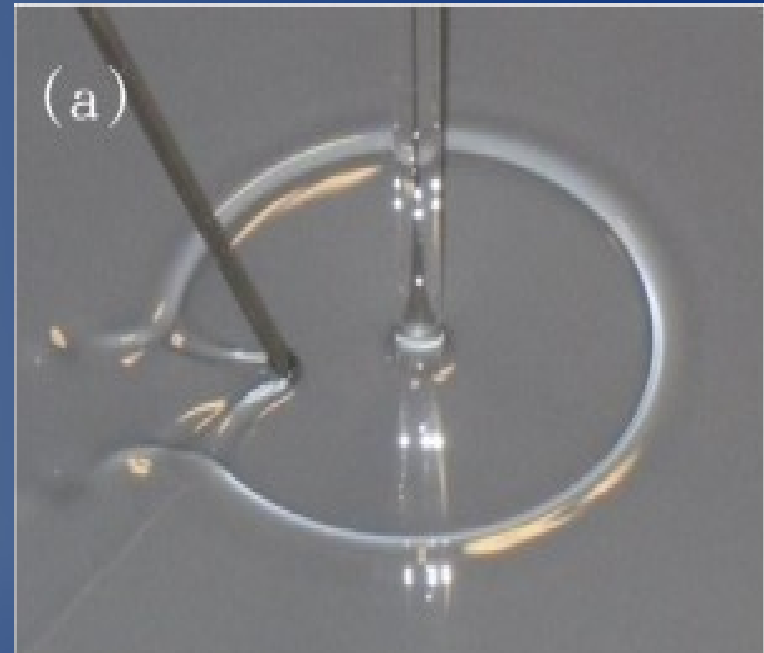


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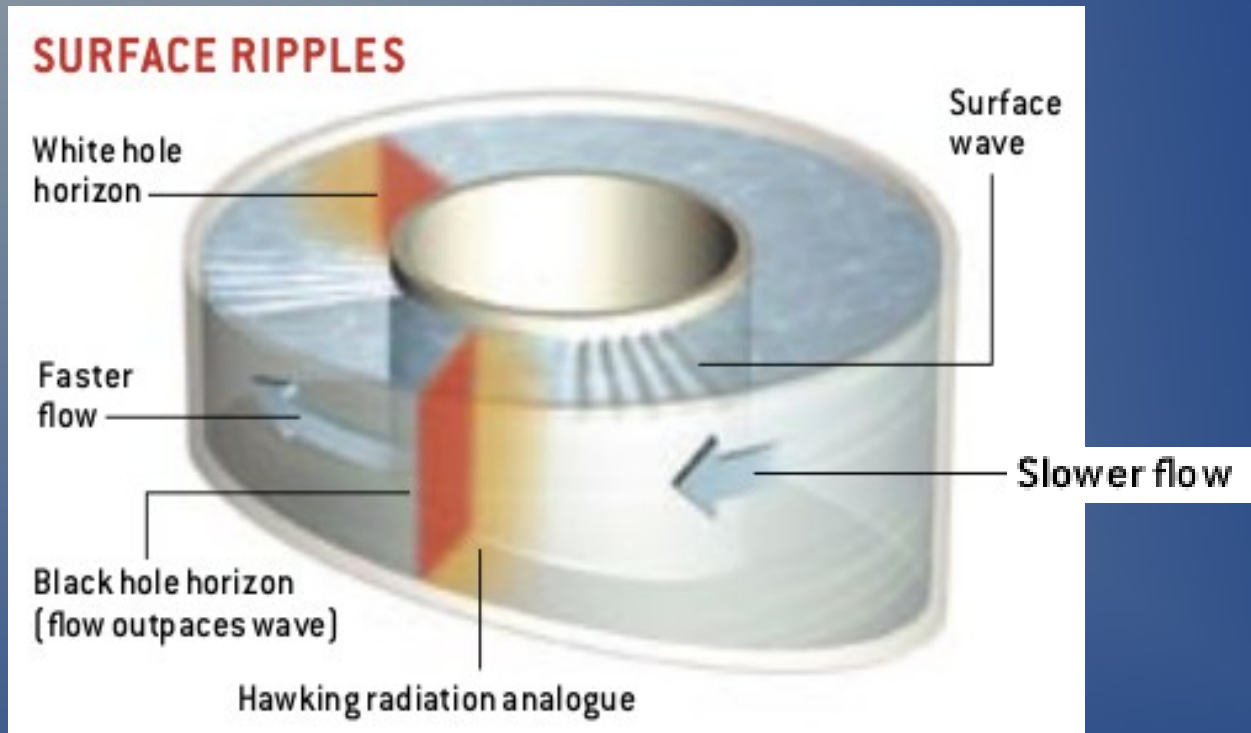




J.W.M. Bush  
(MIT)

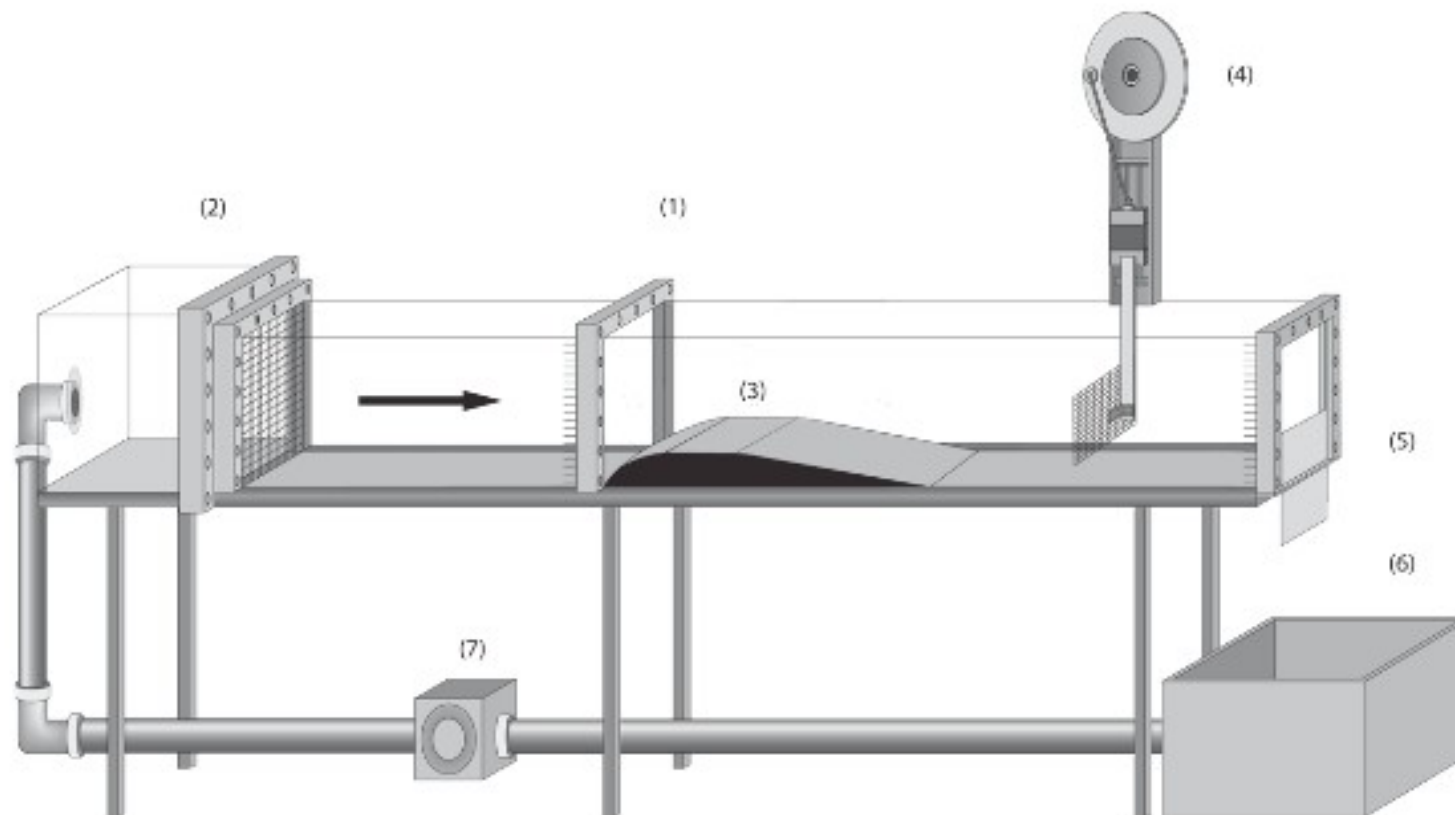
<http://www-math.mit.edu/~bush/jump.htm>

# Proposta experimentais



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## Experiment procedures



**Figure 2 | Experimental apparatus.** The experimental apparatus used in our experiments: (1) flume, (2) intake reservoir, (3) obstacle, (4) wave generator, (5) adjustable weir, (6) holding reservoir, and (7) pump and pump valve.

Physical Review Letters

moving physics forward

Silke Weinfurter<sup>1</sup>, Edmund W. Tedford<sup>2</sup>, Matthew C. J. Penrice<sup>1</sup>, William G. Unruh<sup>1</sup>, and Gregory A. Lawrence<sup>2</sup>

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<sup>2</sup>Department of Civil Engineering, University of British Columbia, 6250 Applied Science Lane, Vancouver, Canada V6T 1Z4