Wave Physics
PHYS 2023
Tim Freegarde
Sumatra-Andaman earthquake 2004

26 DEC 2004 04:15Z

FROM: UN ENVOY SUMATRA
TO: CHIEF SCI ADVISOR LONDON
MAGNITUDE 9.1 EARTHQUAKE ALONG INDIA-BURMA SUBDUCTION ZONE.
1200KM FAULT LEAVING KM-WIDE RIDGES AND TROUGHS.
30 CUBIC-KM WATER DISPLACED.
NOAA SATELLITE RADAR REPORTS
+2HRS WAVE HEIGHT 0.6M
+3HRS WAVE HEIGHT 0.4M
PLS ADVISE ++ UTMOST URGENCY ++
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• NOAA radar was experimental
• data analysis and wave simulation were not possible until days later
• 275,000 people perished
What is a wave?

- Wave examples
- Wave properties
- Wave phenomena
- Wave mechanisms
Water waves

- Ocean waves
- Severn bore
- Kelvin ship wake
- Tsunami
Aerodynamic waves

- Mountain lee waves
- Kelvin-Helmholtz atmospheric waves
- Shock diamonds / Mach discs
Electromagnetic waves

- Light
- Radio
- Gamma radiation
Acoustic waves

- Ultrasound
- Sonar

http://www.scienceinthenews.org.uk/
Acoustic waves

- Ultrasound
- Sonar
- Music

Wolfgang Moroder

http://www.scienceinthenews.org.uk/

Ophélie Gaillard, Bach, Prelude, Cello suite n. 1
Chemical waves

- Belousov-Zhabotinsky (autocatalytic) reaction: $\text{Br}_2 \rightarrow 2 \text{Br}^+ \rightarrow \text{Br}_2 \rightarrow \ldots$
  
Mexican waves

• Stadium waves started by ~dozen people, speed ~12 m s\(^{-1}\), width 6 to 12 m
Mexican waves

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- Prairie dogs’ *jump-yip* displays used to test neighbours’ awareness
  J F Hare, K L Campbell, R W Senkiw, Proc Roy Soc B 281 (1777), 20132153 (2014)
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- Emperor penguins form dense (triangular lattice) *huddle* to conserve heat
- Malaysian giant honey bees perform wave to confuse and deter prey
What is a wave?

- Wave examples
- Wave properties
- Wave phenomena
- Wave mechanisms
## Wave Physics

<table>
<thead>
<tr>
<th>Wave Equations &amp; Sinusoidal Solutions</th>
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<tbody>
<tr>
<td>general wave phenomena</td>
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<tr>
<td>wave equations, derivations and solution</td>
</tr>
<tr>
<td>sinusoidal wave motions</td>
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<tr>
<td>complex wave functions</td>
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<table>
<thead>
<tr>
<th>Wave Propagation</th>
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<tbody>
<tr>
<td>Huygens’ model of wave propagation</td>
</tr>
<tr>
<td>interference</td>
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<tr>
<td>Fraunhofer diffraction</td>
</tr>
<tr>
<td>longitudinal waves</td>
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<table>
<thead>
<tr>
<th>Behaviour at Interfaces</th>
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<tbody>
<tr>
<td>continuity conditions</td>
</tr>
<tr>
<td>boundary conditions</td>
</tr>
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<table>
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<tr>
<th>Superpositions</th>
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<tbody>
<tr>
<td>linearity and superpositions</td>
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<tr>
<td>Fourier series and transforms</td>
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<tr>
<th>Further Topics</th>
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<tbody>
<tr>
<td>waves in three dimensions</td>
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<tr>
<td>waves from moving sources</td>
</tr>
<tr>
<td>operators for waves and oscillations</td>
</tr>
<tr>
<td>further phenomena and implications</td>
</tr>
</tbody>
</table>

Wave Physics

- principal characteristics of waves and wave propagation
- optics, sound, musical instruments, quantum waves
- introduction to electromagnetic waves, quantum mechanics
- a few diversionary examples...

<table>
<thead>
<tr>
<th>LECTURES</th>
<th>1 single + 1 double lecture each week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lecture notes and directed reading</td>
</tr>
<tr>
<td>CLASSES</td>
<td>once a week (Tuesday 1 o’clock)</td>
</tr>
<tr>
<td></td>
<td>identify difficulties beforehand!</td>
</tr>
<tr>
<td>COURSEWORK</td>
<td>weekly sheets of exercises</td>
</tr>
<tr>
<td></td>
<td>hand in on level 3</td>
</tr>
<tr>
<td></td>
<td>20%</td>
</tr>
<tr>
<td>EXAMINATION</td>
<td>a: 5 short questions</td>
</tr>
<tr>
<td></td>
<td>b: 2 longer questions</td>
</tr>
<tr>
<td></td>
<td>80%</td>
</tr>
</tbody>
</table>
Wave Physics resources

You should expect to make use of:

- lectures, hand-outs and your own lecture notes
- textbooks - some suggestions in following slide
- exercises and classes:

  week $n$
  
  week $n+1$
  
  week $n+2$

- for handouts, links and other material, see http://phyweb.phys.soton.ac.uk/quantum/phys2023.php
Wave Physics ‘feedback’

To help you assess your progress and improve:

- weekly coursework will be returned with marks and comments
- weekly problems classes offer individual help
- tutors can give additional help
- some past exam papers have model answers
- lecturer ‘at home’: Tuesdays 4:00-5:00
- email me!

- for handouts, links and other material, see http://phyweb.phys.soton.ac.uk/quantum/phys2023.php
Textbooks

Freegarde *Introduction to the Physics of Waves*
► written for THIS course!

Pain *Physics of Vibrations & Waves*
► good: right level, comprehensive

Main *Vibrations & Waves in Physics*
► reasonable, but dated and slim

French *Vibrations & Waves*
► quite good, concise

Crawford *Waves*
► brilliant! (out of print)

Coulson & Jeffries *Waves*
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Feynman *Lectures on Physics*
► excellent introduction: put on your Christmas list!

Pretor-Pinney *Wavewatcher's Companion*
► brilliantly readable general account
**Textbooks**

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Hartley library can lend paper and electronic copies

Physics library has some reference volumes
What is a wave?

- Wave examples
- Wave properties
- Wave phenomena
- Wave mechanisms
Wave Physics

Local/microscopic definition:

- a collective bulk disturbance in which what happens at any given position is a delayed response to the disturbance at adjacent points

- speed of propagation is derived

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<tr>
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<tr>
<td>static</td>
<td>equilibrium</td>
<td>eg Poisson’s equation</td>
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<tr>
<td>dynamic</td>
<td>SHM</td>
<td>WAVES</td>
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Electromagnetic waves

\[ F = \frac{q_1 q_2}{4\pi \varepsilon_0 r^2} \]

- vertical component of force

\[ F_\uparrow(t) = q_2 \left( \frac{q_1}{4\pi \varepsilon_0 r^3} \right) a(t) \]
Electromagnetic waves

- Vertical component of force: \( F_\uparrow(t) = q_2 \frac{q_1}{4\pi \varepsilon_0 r^3} a(t) - \frac{r}{c} \)

- Delay may be due to propagation speed of force (retarded potentials)

- Electric field = force per unit charge (\( q_2 \))
Gravitational waves

- vertical component of force
  \[ F_{\uparrow}(t) = \frac{\mu m_1 m_2}{4\pi\varepsilon_0 r^3} \alpha \left( t - \frac{\sqrt{r^2}}{c} \right) \]

- delay due to propagation of force (retarded potentials)

- gravitational fields for equal mass bodies

- centre of mass motion → quadrupole radiation
Gravitational waves

- Verlizing moment of force on neutron stars, \( m, 1.4 \) solar mass
- separation few tens of km
- several rotations per second
- stars coalesce after minutes
- gravitational field = force per unit mass \( (m) \)
- detector is laser interferometer several km in size
- centre of mass motion \( \rightarrow \) quadrupole radiation
Wave Physics

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Macroscopic definition:

- a time-dependent feature in the field of an interacting body, due to the finite speed of propagation of a causal effect

- speed of propagation is assumed
Wave Physics

Local/microscopic definition:

- a collective bulk disturbance in which what happens at any given position is a delayed response to the disturbance at adjacent points
- speed of propagation is derived

What is the net force on the penguin?

\[ \mathcal{F} = -\frac{\partial P}{\partial x} \delta x \]

For an elastic penguin, Hooke’s law gives

\[ P = -C \frac{\partial y}{\partial x} \]

If the penguin has mass \( m \), Newton’s law gives

\[ \mathcal{F} = m \frac{\partial^2 y}{\partial t^2} \]

where \( m = \rho \delta x \)

- rest position \( x \)
- separation \( \delta x \)
- displacement \( y \)
- pressure \( P \)
- elasticity \( C \)
- density \( \rho \)
First exercise sheet

Revision of mathematical prerequisites:

- sinusoidal functions and complex exponentials
- trigonometric identities
- differentiation and integration

For handouts, links and other material, see
Plucked guitar string

- displace string as shown
- at time $t = 0$, release it from rest
- ...What happens next?
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