







EGY Plasma

Nature's Secrets: The Pathway to Plasma

Waleed Moslem Port Said University The British University

Aim of the lecture

The Evolution of Scientific Research in Plasma

through Natural Observation in Physics

From Nature to Physics: Shaping Our Modern World

- Nature \rightarrow Matter, Motion, Energy, Force \rightarrow Physics \rightarrow Understanding the Universe's Behavior:
- Laws of physics explain how matter and energy interact → from the smallest particles to the largest cosmic structures.
- 2) **Observation of nature** \rightarrow lead to the discovery of these laws \rightarrow helping us understand the forces and motions that govern the universe.

From Nature to Physics: Shaping Our Modern World

- Development of New Products → Modern Society Improvement
- 1) Innovations in physics → new technologies and products
 → contribute to societal progress → boosting industries, economies
- 2) Understanding the principles of nature and physics \rightarrow we can continue advancing science and technology





قطار شينكانسن



الرفراف











- تصميم بدل الغواصة
- شركات تصنيع السفن الكبرى مثل BAE Systems وRolls Royce

Marine استخدمت مفاهيم مستوحاة من جلد القرش لتطوير طلاءات

- ذكية مقاومة للسحب _ توفير وقود.
- الدهانات الخاصة التي تقلل نمو البكتيريا على الأسطح في المستشفيات
- طلاءات الغواصات: لا تقلل فقط الاحتكاك، بل قد تستخدم تقنيات
 - 7/85 لامتصاص الموجات الصوتية أيضًا (عزل صوتي)

Outline

- Soliton
- Cnoidal
- Tsunami
- Envelope soliotn
- Rogue wave
- Mach Cones
- Wakefield

- Water droplet
- St. Elmo's fire
- AGN
- Instabilities & Fusion

Soliton

- In 1834, while conducting experiments to determine the most efficient design for canal boats, he discovered a phenomenon that he described as the **wave of translation**
- Stable Large distances Speed(size) – Width(depth) – Never merge – Splits into two waves



John Scott Russell (1808-1882) _{9/85}



J. S. Russell Aqueduct

- 89.3 m long
- 4.13 m wide
- 1.52 m deep



ON WAVES.

Report on Waves. By J. SCOTT RUSSELL, Esq., M.A., F.R.S. Edin., made to the Meetings in 1842 and 1843.

Members of Committee Sir JOHN ROBISON*, Sec. R.S. Edin. J. SCOTT RUSSELL, F.R.S. Edin.

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A PROVISIONAL Report on this subject was presented to the Meeting held at Liverpool in 1838, and is printed in the Sixth Volume of the Transactions. That report was a partial one. It states that "the extent and multifarious nature of the subjects of inquiry have rendered it impossible to terminate the examination of all of them in so short a time; but it is their duty to report the progress which they have made, and the partial results they have already obtained, leaving to the reports of future years such portions of the inquiries as they have not yet undertaken."

The first of these subjects of inquiry is stated to have been "to determine the varieties, phænomena and laws of waves, and the conditions which affect their genesis and propagation."

It is this branch of the duty of the Committee which forms the subject of the present report. Ever since the date of that report, it has happened that the author of this has been so fully pre-occupied by inevitable duty, that it was not in his power to indulge much in the pleasures of scientific inquiry; and as the active part of the investigation necessarily devolved upon him, it was not practicable to continue the series of researches on the amplé and systematic scale originally designed, so soon as he had anticipated, so that the former report has necessarily been left in a fragmentary state till now.

But I have never ceased to avail myself of such opportunities as I could contrive to apply to the furtherance of this interesting investigation. I have now fully discussed the experiments which the former report only registered. I have repeated the former experiments where their value seemed doubtful, I have supplemented them in those places where examples were wanting. I have extended them to higher ranges, and where necessary to a much larger scale. In so far as the experiments have been repeated and more fully discussed, they have tended to confirm the conclusions given in the former report, as well as to extend their application.

The results here alluded to are those which concern especially the velocity and characteristic properties of the solitary wave, that class of wave which the writer has called the great wave of translation, and which he regards as the primary wave of the first order. The former experiments related chiefly to the mode of genesis, and velocity of propagation of this wave. They led to this expression for the velocity in all circumstances,

$v = \sqrt{g(h+k)},$

A being the height of the crest of the wave above the plane of repose of the fluid, h the depth throughout the fluid in repose, and g the measure of gravity. Later discussions of the experiments not only confirm this result, but are themselves established by such further experiments as have been recently instituted, so that this formerly obtained velocity may now be regarded as the phenomenon characteristic of the wave of the first order.

The former series of experiments also contained several points of research not published in the former report, because not sufficiently extended to be of

* I cannot allow these pages to leave my hands without expressing my deep regret that the death of Sir John Robison has suddenly deprived the Association of a zealous and distinguished office-bearer, and myself of a kind friend. In all these researches the responsible duties were mine, and I alone am accountable for them; but in forwarding the objects of the investigation I always found him a valuable counsellor and a respected and cordial cooperator.

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Diederik Johannes Korteweg (1848 – 1941) Gustav de Vries (1866 – 1934)



Korteweg-de Vries Equation (1895)

Linear & Nondispersive



Nonlinear & Nondispersive



Linear & Dispersive



Nonlinear & Dispersive



- Zabusky & Kruskal (1965) → numerically → solutions seemed to decompose at large times into a collection of "solitons"
- Soliton in: shallow-water waves, plasma, crystal lattice, biology, optical fiber
- Movie1 and Movie2

VOLUME 17, NUMBER 19 PHYSICAL REVIEW LETTERS

7 November 1966

PROPAGATION OF ION-ACOUSTIC SOLITARY WAVES OF SMALL AMPLITUDE

Haruichi Washimi and Tosiya Taniuti Institute of Plasma Physics, Nagoya University, Nagoya, Japan (Received 5 August 1966)

VOLUME 25, NUMBER 1

PHYSICAL REVIEW LETTERS

6 July 1970

FORMATION AND INTERACTION OF ION-ACOUSTIC SOLITONS*

H. Ikezi, † R. J. Taylor, ‡ and D. R. Baker Department of Physics, University of California, Los Angeles, California 90024 (Received 11 May 1970)

Cnoidal

- Korteweg and de Vries \rightarrow 1895 \rightarrow KdV Eq.
- Jacobi elliptic function *cn*, which is why they are coined *cnoidal* waves
- In the limit of infinite wavelength → the cnoidal wave becomes a solitary wave.

Cnoidal, cont.



Surface water waves & Ion-acoustic waves in plasma physics & Optical fiber & Graphene-based superlattice & Solids & Traffic flow.....etc

Cnoidal, cont. PROCEEDINGS THE ROYAL MATHEMATICAL OF OF SOCIETY OF SCIENCES

On cnoidal waves and bores

Department of Engineering, University of Cambridge

AND M. J. LIGHTHILL, F.R.S. Department of Mathematics, University of Manchester

(Received 13 February 1954)

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN, Vol. 46, No. 6, JUNE, 1979

Propagation of Ion Acoustic Cnoidal Wave

Kimiaki Konno, Teruo Mitsuhashi[†] and Yoshi H. Ichikawa^{††}

Department of Physics, College of Science and Technology, Nihon University, Tokyo [†]Shiroyama Senior High School, Shiroyama, Kanagawa [†]Institute of Plasma Physics, Nagoya University, Nagoya

(Received February 5, 1979)

Tsunami

• What do you do if you're at the beach and the sea is receding farther than usual?



Before the earthquake

The plate holding the Indian Ocean was sliding under the continental plate (holding Indonesia and much of Asia) at about 6 cm per year. The continental crust was bent thanks to the constant pressure of collision.



2 During the quake

The fault ruptured violently, allowing the continental crust to unbend and causing portions of the sea floor to move up or down by several metres. The water above the fault responded in kind, creating a wave crest and trough.



3 The wave travels

One wave crashed towards the nearby shore of Indonesia. Another barrelled westwards at about 800 km per hour in deep water, with a wavelength of 100 km and an average wave height of just tens of centimetres.



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4 Collision

When the wave entered shallow waters, it slowed to tens of kilometres per hour, its wavelength shortened to about 5 km, and its height is thought to have soared to more than ten metres. The trough of the wave often hits before the crest (as shown).



Movie

- Mathematics helps predict and reduce tsunami dangers by modeling their behavior.
- Mathematical models simulate the creation and propagation of tsunami waves in the ocean.
- These models **clarify key tsunami wave characteristics**, such as speed, height, and energy.
- Engineers use this data to design effective early warning systems.
- Early warning systems help protect lives and reduce damage by alerting communities before a tsunami strikes.



A LETTERS JOURNAL EXPLORING THE FRONTIERS OF PHYSICS

November 2009

EPL, **88** (2009) 45001 doi: 10.1209/0295-5075/88/45001 www.epljournal.org

Steepening of solitons (tsunami effect) in complex plasmas

C. Durniak $^{1(a)},$ D. Samsonov 1, S. Zhdanov 2 and G. Morfill 2

IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 39, NO. 11, NOVEMBER 2011

Tsunami in a Complex (Dusty) Plasma

D. Samsonov, C. Durniak, S. Zhdanov, and G. Morfill

Soliton & Cnoidal & Tsunami

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Envelope Soliotn



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Envelope Soliotn

 $\psi_1 = A\cos(k_1x - \omega_1t), \qquad \psi_2 = A\cos(k_2x - \omega_2t)$

$$\psi = A(x, t) \cos(k_0 x - \omega_0 t)$$



Movie

- The amplitude of the harmonic wave may vary in space and time
- Time scales. How many time scales?



- This modulation due to nonlinearity may be strong enough to lead to the formation of envelope soliton
- Three forms of envelope: bright, dark, and Gray
- Evolution equation \rightarrow Nonlinear Schrödinger Eq.

$$i\frac{\partial\psi}{\partial\tau} + P\frac{\partial^2\psi}{\partial\zeta^2} + Q\left|\psi\right|^2\psi = 0$$



JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN, Vol. 27, No. 5, NOVEMBER, 1969

A Nonlinear Theory of Two-Stream Instability

Tsuguhiro WATANABE

PERTURBATION METHODS

ALI HASAN NAYFEH

Professor of Engineering Science and Mechanics Virginia Polytechnic Institute and State University Blacksburg, Virginia 24061

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J. Plasma Physics (1975), vol. 14, part 2, pp. 353-364

Ion-acoustic solitons excited by a single grid By S. WATANABE

J. Plasma Physics (1976), vol. 15, part 1, pp. 67-81

Effect of wave-particle interaction on recurrence of a nonlinear ion wave

By S. WATANABE

- 1973: Akira Hasegawa of AT&T Bell Labs was the first to suggest that envelope solitons could exist in optical fibers
- 1973: Robin Bullough made the first mathematical report of the existence of optical solitons → suggest its application in optical telecommunications
- 1987: Emplit et al. made the first experimental observation of the propagation of a dark soliton, in an optical fiber
- 1970's: Starting the Nonlinear Plasma Physics Era_{34/85}

Rogue wave



Freak waves









Extreme waves





Rogue waves





- H_{max} =25.6 m & 1 in 200,000 waves
- Extreme waves \rightarrow appear from nowhere \rightarrow high-energy \rightarrow high amplitude \rightarrow carry dramatic impact
- How this wave exist? \rightarrow Use & Avoid
- Movie 1
VOLUME 88, NUMBER 7

PHYSICAL REVIEW LETTERS

18 February 2002

Experimental Evidence for Soliton Explosions

Steven T. Cundiff,^{1,*} J. M. Soto-Crespo,² and Nail Akhmediev³

We show, experimentally and numerically, that Ti:sapphire mode-locked lasers can operate in a regime in which they intermittently produce exploding solitons. This happens when the laser operates near a critical point. Explosions happen spontaneously, but external perturbations can trigger them. In stable operation, all explosions ha depend on the intracavity



Eur. Phys. J. Special Topics **185**, 169–180 (2010) © EDP Sciences, Springer-Verlag 2010 DOI: 10.1140/epjst/e2010-01247-6

THE EUROPEAN PHYSICAL JOURNAL SPECIAL TOPICS

Regular Article

Vector rogue waves in binary mixtures of Bose-Einstein condensates

Yu.V. Bludov^{1,a}, V.V. Konotop^{2,b}, and N. Akhmediev^{3,c}

Abstract. We study numerically rogue waves in the two-component Bose-Einstein condensates which are described by the coupled set of two Gross-Pitaevskii equations with variable scattering lengths. We show that rogue wave solutions exist only for certain combinations of the nonlinear coefficients describing two-body interactions. We present the solutions for the combinations of these coefficients that admit the existence of rogue waves.



Commun. Theor. Phys. (Beijing, China) **54** (2010) pp. 947–949 © Chinese Physical Society and IOP Publishing Ltd

Vol. 54, No. 5, November 15, 2010

Financial Rogue Waves^{*} YAN Zhen-Ya (闫振亚)[†] Key Laboratory of Mathematics Mechanization, Institute of Sy Beijing 100190, China (Received June 4, 2010) $|\psi|^2$ 100 $|\psi|^2$ 100 $|\psi|^2$ 100 $\int_{0}^{0} \frac{1}{\sqrt{2}} \int_{0}^{0} \frac{1}{\sqrt{2}$

Abstract We analytically give the financial rogue waves in the nonlinear option pricing model due to Ivancevic, which is nonlinear wave alternative of the Black–Scholes model. These rogue wave solutions may be used to describe the possible physical mechanisms for rogue wave phenomenon in financial markets and related fields.

Eur. Phys. J. Special Topics **185**, 57–66 (2010) © EDP Sciences, Springer-Verlag 2010 DOI: 10.1140/epjst/e2010-01238-7

THE EUROPEAN PHYSICAL JOURNAL SPECIAL TOPICS

Regular Article

Freak waves in laboratory and space plasmas

Freak waves in plasmas

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Received in final form and accepted 15 June 2010 Published online 23 August 2010

- How to create/control rogue waves?
- Why?
- Movie 1

PHYSICAL REVIEW X 2, 011015 (2012)

Time (s)

Super Rogue Waves: Observation of a Higher-Order Breather in Water Waves

A. Chabchoub,^{1,*} N. Hoffmann,¹ M. Onorato,^{2,3} and N. Akhmediev⁴

PRL 107, 255005 (2011)

PHYSICAL REVIEW LETTERS

week ending 16 DECEMBER 2011

Observation of Peregrine Solitons in a Multicomponent Plasma with Negative Ions

H. Bailung,¹ S. K. Sharma,¹ and Y. Nakamura^{1,2}

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JOURNAL OF GEOPHYSICAL RESEARCH: SPACE PHYSICS, VOL. 118, 919-924, doi:10.1002/jgra.50111, 2013

Observation of hole Peregrine soliton in a multicomponent plasma with critical density of negative ions

S. K. Sharma, and H. Bailung



nature physics

PUBLISHED ONLINE: 29 FEBRUARY 2016 | DOI: 10.1038/NPHYS3669

Generation of acoustic rogue waves in dusty plasmas through three-dimensional particle focusing by distorted waveforms

Ya-Yi Tsai, Jun-Yi Tsai and Lin I*



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FRS

Mach Cones

- When an object moves through the air it pushes the air in front of it away, creating a pressure wave.
- This pressure wave travels away from the object at the speed of sound.
- If the object itself is traveling at the speed of sound then these pressure waves build up on top of each other to create a shock wave





Mach Cones, cont.



- The black object in the center is a projectile or supersonic body (e.g., bullet or airfoil).
- The V-shaped lines in front are shock waves, specifically a bow shock from supersonic motion.
- The patterns behind the object show turbulent wake and flow separation.



Mach Cones, cont.

VOLUME 83, NUMBER 18

PHYSICAL REVIEW LETTERS

1 NOVEMBER 1999

Mach Cones in a Coulomb Lattice and a Dusty Plasma

D. Samsonov, J. Goree,* Z. W. Ma, and A. Bhattacharjee

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H. M. Thomas and G. E. Morfill

Max Planck Institut für extraterrestrische Physik, 85740 Garching, Germany



Mach Cones, cont.

PHYSICAL REVIEW E

VOLUME 61, NUMBER 5

MAY 2000

Mach cone shocks in a two-dimensional Yukawa solid using a complex plasma

D. Samsonov^{*} and J. Goree[†]

Department of Physics and Astronomy, The University of Iowa, Iowa City, Iowa 52242

H. M. Thomas and G. E. Morfill

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Wakefield









wave in the wake of a boat

• There were two early ideas on plasma accelerators: *beatwave* and *wakefield*.



- In 1979 John Dawson, in a paper with T. Tajima, proposed that Landau damping effect could be used to accelerate particles
- In plasma, there are electrons both faster and slower than the wave.

Phys. Fluids, Vol. 28, No. 7, July 1985 Attractive potential between resonant electrons

M. Nambu and H. Akama College of General Education, Kyushu University, Ropponmatsu, Fukuoka 810, Japan

Physics Letters A 203 (1995) 40–42 Attractive forces between charged particulates in plasmas

Mitsuhiro Nambu, Sergey V. Vladimirov¹, Padma K. Shukla²

The charged particles having the same polarity can attract each other...!!





- **Vph** ~ **Cs**
- Appearing long-range oscillatory wakefield
- The background **positive ions are trapped** in the negative part of the oscillatory wake potential.
- The negative charges are attracted to each other as they are glued by positive ions in a linear chain 55/85

PRL 95, 054802 (2005)

PHYSICAL REVIEW LETTERS

week ending 29 JULY 2005

Multi-GeV Energy Gain in a Plasma-Wakefield Accelerator



- J. Decker,¹ S. Deng,³ P. Emma,¹ C. Huang,² R. H. Iverson,¹ D. K. Johnson,² Lu,² K. A. Marsh,² W. B. Mori,² P. Muggli,³ C. L. O'Connell,¹ E. Oz,³ R. H. Siemann,¹ and D. Walz¹
 - In vacuum (left): The electron pulse retains a uniform energy around 28.5 GeV, showing no significant energy change.
 - In plasma (right): The front electrons lose energy forming the wake, while backward electrons are accelerated to energies above 28.5 GeV, reaching up to ~31 GeV.
 - The image visualizes energy variation, not position, since all electrons are moving at nearly the speed of light. 56 / 85

Summary (H.W.)

TERMINOLOGY

- Soliton
- Cnoidal
- Tsunami
- Envelope soliotn
- Rogue wave
- Mach Cones
- Wakefield

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CONCEPT

Water droplet



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Water droplet, cont.





Water droplet, cont.





Water droplet, cont.





St. Elmo's fire

- Blue or violet ball with a hissing sound that constitutes Saint Elmo's fire is different from fire and lightning.
- Ship mast should start St. Elmo's fire, airplane wing...



St. Elmo's fire, cont.



St. Elmo's fire, cont.

- Gas glows with proton clusters and electrons under high voltage
- Air is good electrical insulation. If a metal rod's end has a high electric field, air molecules nearby are ionized and charges flow off
- These "corona discharges" light softly in the dark. The St. Elmo fire is a corona discharge. It's not lightning
- Mast seems like fire but does not burn
- Low temperature plasma

Movie

Active Galactic Nuclei





Active Galactic Nuclei, cont.



Active Galactic Nuclei, cont.

Wound Healing: Suppurated Burns



Plasma Technologies, Inc





therapy (5 sessions).



Wound Healing: Trophic Venous Ulcers







Active Galactic Nuclei, cont.



Plasma thruster

Lightning



- Plasma arc recycling
- Movie



Kelvin–Helmholtz Instability

- Velocity shear in a single continuous fluid
- Velocity difference across the interface between two fluids





Movie

Rayleigh–Taylor Instability



When the lighter fluid is pushing the heavier fluid

Rayleigh–Taylor, cont.




Sawtooth instability





Sawtooth instability



Sausage instability



Sausage instability



Ballooning Instability



Ballooning Instability



Tearing Mode



Tearing Mode



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Fusion Energy

How nuclear fusion works

1	2	3	4
Hydrogen atoms are heated	Fusion reaction	Helium, neutron and energy released	Neutron energy heats water



/ 85

BBC

Fusion Energy



Wendelstein 7-X stellarator

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Fusion Energy

Inertial confinement fusion







