

Physics World Archive

Electrons surf to high energies on plasma waves

Alan Cairns

**From
Physics World
February 1996**

© IOP Publishing Ltd 2010

ISSN: 0953-8585

IOP

**Institute of Physics Publishing
Bristol and Philadelphia**

Downloaded on Fri Dec 03 20:25:27 GMT 2010 [128.97.89.176]

Electrons surf to high energies on plasma waves

From **Alan Cairns** in the School of Mathematical and Computational Sciences, University of St Andrews, UK

THE accelerators used by particle physicists need to be many kilometres long to reach the energies at which new particles such as the Higgs boson are expected to be found. The particles are accelerated by electric fields, and accelerator designers are always looking for ways to increase the electric field strength since this will reduce the length of the machine. One possibility that has been investigated over the past decade is the use of plasma waves in laser-produced plasmas. The electric field in a large-amplitude plasma wave can be orders of magnitude stronger than the fields produced in conventional accelerators. The downside is that the plasma medium cannot be controlled as precisely as metal conductors, so replacing the large machines required for high-energy physics with plasma-based accelerators is still a distant dream.

However, an important advance in particle acceleration to more modest energies has recently been demonstrated at the Rutherford Appleton Laboratory (RAL) in the UK (A Modena *et al.* 1995 *Nature* 377 606). A team from Imperial College in London, the University of California at Los Angeles, the Ecole Polytechnique in Palaiseau, France, the Lawrence Livermore National Laboratory in California and RAL used the VULCAN laser at Rutherford to accelerate electrons up to energies of 44 MeV in a well collimated beam. The electrons were accelerated by the plasma wave produced when a short, high-intensity laser pulse from VULCAN was focused onto a gas target.

The electric field in the plasma wave is produced by differences in the electron and ion charge densities in the plasma. The field is both periodic and parallel to the wave propagation direction (i.e. the wave is longitudinal). The plasma wave produced by a laser can have both a large amplitude and a phase velocity close to the speed of light, and a particle moving with the wave is accelerated by this field, rather like a surfer on a water wave.

So far, most discussion of plasma accelerators has focused on either "beat wave" or "wake field" schemes. In the beat wave scheme, two laser pulses that differ in frequency by the plasma frequency – the characteristic frequency of longitudinal

oscillations in the plasma – interact as they propagate through the plasma. This generates a driving force at the beat frequency, which, being in resonance with the plasma wave, drives it up to a high amplitude. In the wake field scheme, a single laser pulse leaves a wake, consisting of a plasma wave, behind it. The laser pulse must be shorter than one wavelength of the plasma wave.

However, the present experiments used single-frequency pulses that were too long to generate a wake. Therefore the large-

electromagnetic waves interacting to drive up the plasma wave. The difference is that the second wave is driven up from noise rather than being generated externally. This has the advantage that the frequency difference of the waves automatically matches the plasma frequency, and thus the careful control of the plasma density that is needed for a successful beat wave experiment is not necessary.

The experiments used 25 TW, 0.8 ps pulses focused to a 20 μm spot on the edge of a 4 mm diameter plume of helium gas from a pulsed supersonic gas jet. The most important diagnostics measured the scattered wave spectrum and the electron energy spectrum in the forward direction. The best results were obtained at the highest gas density used, $1.5 \times 10^{19} \text{ cm}^{-3}$, giving an electron energy spectrum essentially flat up to 30 MeV, falling off slowly up to the detector limit of 44 MeV. Although the higher value is the greatest energy claimed by the team, it seems reasonable to suppose that the spectrum continues up to substantially higher energies. This acceleration is accompanied by a tremendous broadening of the scattered wave spectrum.

The acceleration is likely to be the result of wave breaking. The wave grows until the potential wells associated with the longitudinal wave field become deep enough to trap particles in the main part of the thermal distribution of electrons. Substantial numbers of particles are then accelerated up to relativistic energies. At the same time the coherence of the wave is destroyed. The process is analogous to the familiar breaking of a water wave where liquid at the crest of the wave is thrown forward and the coherent wave breaks up.

Compared with a conventional particle accelerator, the system produces beams with a transverse emittance that matches those of photoinjector-based linacs, but with a current that is between 10 and 100 times less. However, the acceleration length is estimated to be only a few hundred micrometres, and the inferred peak electric field is of the order of 100 GV m^{-1} , the highest collective field produced to date in a laboratory. Although VULCAN is a large system, advances in laser technology make it possible to envisage compact laser-based accelerators producing electrons in the range from a few MeV to a few hundred MeV in the not too distant future. □



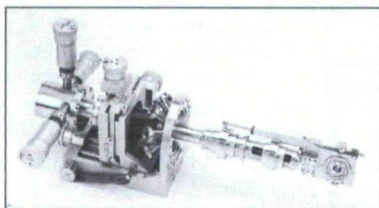
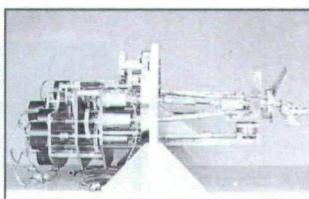
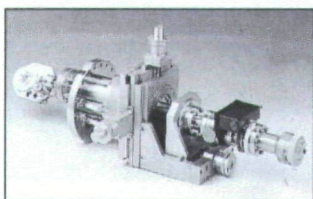
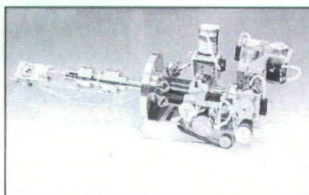
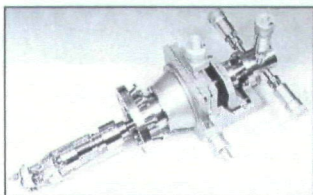
Preparing a short-pulse electron acceleration experiment using the VULCAN laser at the Rutherford Appleton Laboratory.

amplitude plasma wave producing the acceleration was attributed to a third mechanism: forward Raman scattering. This process involves the resonant excitation of a second or "decay" electromagnetic wave and a longitudinal plasma wave by an electromagnetic pump wave (such as a laser). Backward Raman scattering, in which the decay electromagnetic wave travels in the opposite direction to the incident wave, has been investigated in detail because it is thought to prevent effective energy absorption by the solid targets used in laser-fusion experiments.

In the less dense gas targets of the present experiments, forward Raman scattering occurs with the incident and decay waves parallel. The generated plasma wave has a high phase velocity, which can be close to that of light under suitable conditions. In essence, the process is similar to the beat wave scheme, with two

ULTRA HIGH VACUUM

High Precision: Goniometers – Manipulators
 XYZ Translators – Rotary Motion Drives
 Rotary/Linear Motion Drives – Stepper Motor Drive Systems
 Designed and Manufactured to suit Customers Specifications

**Panmure Instruments Limited**

3 Bone Lane, Newbury, Berkshire
 RG14 5TE, England.
 Telephone: Newbury (01635) 42305
 Fax: (01635) 528221



INSERT 11 ON REPLY CARD

Metals & Alloys

Foils Wires Rods Tubes

The competitive source for all your requirements
 Shipments within 24 hours Prompt response to enquiries



Competitive prices
Fast shipment
Small quantities
550 Stock lines
3000 Standard packs
Purity 99.9% - 99.999%
METALS
 Al Be Cd Co Cu Au Hf
 In Ir Fe Pb Mg Mo Ni
 Nb Pd Pt Re Rh Si Ag
 Ta Sn Ti W V Zn Zr
ALLOYS
 Al Bi Cu Au Fe
 Mg Ni Pt W

Free Catalogue

Advent Research Materials Ltd
 Blyth Road Industrial Estate
 Halesworth · Suffolk · England IP19 8DD

ADVENT

Telephone 01986 874555
 International +44 1986 874555
 Fax 01986 874557
 International +44 1986 874557

INSERT 12 ON REPLY CARD

Vacuum & Semiconductor Processing

Exhibition**Product Demonstrations****Technical Seminars**

Vac + Semi ... at The Forum, Livingston, Scotland
 June 12/13 1996

Exhibitors from throughout Europe showing the latest in Vacuum Technology, Semiconductor Processing Equipment, Instrumentation, Cleanrooms and Consumables

☐ I would like to visit Vacuum & Semiconductor Processing. Please send me ☐ free tickets

**Tel: on 01822 617744**

International +44 1822 617744

**Fax on 01822 614818**

International +44 1822 614818

FREEPOST

or mail the coupon to:
 Trident Exhibitions Ltd, FREEPOST, Tavistock, Devon,
 PL19 0BR, England

Dr/Mr/Ms/Other	Initials
Surname	
Job Title	
Company	
Address	
Town/City	Postcode
County	Country
Tel	
Fax	

☐ I am interested in exhibiting, please send details

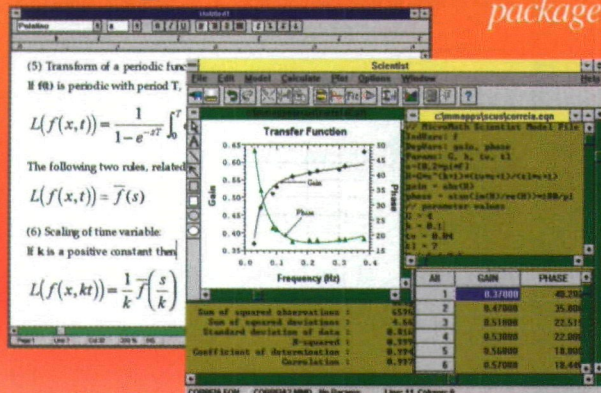
A Trident Event

Trident Exhibitions Ltd, West Devon Business Park, Tavistock, Devon PL19 9DP, England
 Tel: +44 (0)1822 614671 Fax: +44 (0)1822 614818

INSERT 13 ON REPLY CARD

SCIENTIST[®] for WINDOWS[™]

the Experimental Data Fitting package from MicroMath



Version 2 now includes:

- WYSIWYG equation editing for technical document preparation.
- Improved graphics interaction with "tabbed" dialog boxes.
- Superior text editing capabilities.
- Expanded documentation with many example calculations.

SCIENTIST for Windows was designed from the ground up to fit model equations to experimental data. The culmination of over eight years of software development, SCIENTIST integrates and extends four previous MicroMath products into one powerful package devoted to simulation and data fitting. Fit simple equations, or fit combinations or systems of nonlinear algebraic equations, differential equations and Laplace transforms—or fit a variety of interpolating or least squares splines and polynomials. Also includes 3D line and surface plotting, and a built-in worksheet with dimensional analysis, error propagation, unit conversion/factoring, WYSIWYG equation editing, and IEEE expression evaluation.

© 1994 MicroMath Scientific Software, P.O. Box 21550, Salt Lake City, Utah 84121 • 801-943-0290

"If you do much mathematical work, you should be aware of MicroMath. Recommended."

Dr. Jerry Pournelle, BYTE Magazine

SCIENTIST FROM MICROMATH

800-942-MATH Fax 801-943-0299



\$395.00

INSERT 6 ON REPLY CARD

PHYSICS ^{world} Buyer's Guide 96/97

The new edition of the **Physics World Buyer's Guide** has just been published. It will NOT be sent out indiscriminately: to receive your copy you MUST request it.

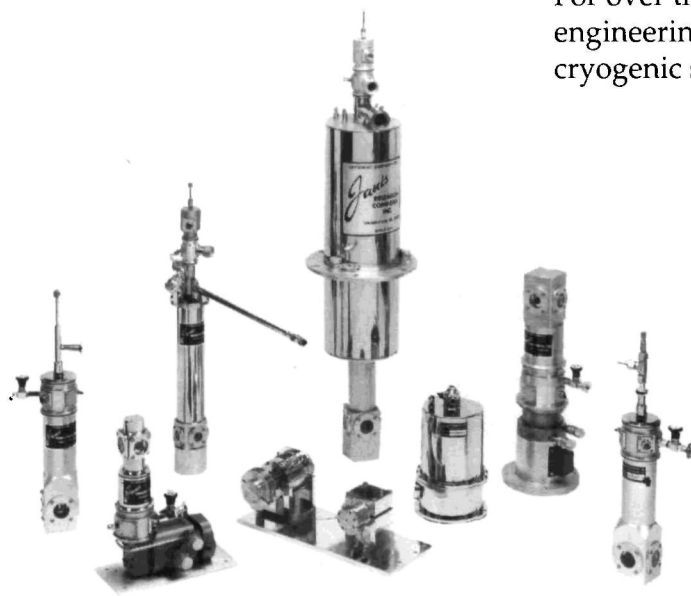
Do this by entering 199 on the reader enquiry card in this magazine and returning it postage-paid today.

The *Physics World Buyer's Guide* is free to IOP members and *Physics World* subscribers resident in the UK. Outside the UK, members and subscribers may order copies for £5 postage and handling charge (prepaid only, with cheques payable to IOP Publishing Ltd). All others may purchase copies at £29.95 each; or receive the *Physics World Buyer's Guide* 1996/97 free by subscribing NOW to *Physics World* magazine – see the subscription card in this copy.

JANIS

CRYOGENIC SYSTEMS

For over thirty years, Janis has combined extensive engineering and fabrication capabilities to design cryogenic systems for virtually any application:



Standard systems include:

- LHe and LN₂ variable temperature and continuous flow cryostats
- Closed Cycle Refrigerators
- Detector Cooling Systems
- Superconducting Magnet Systems
- Dilution Refrigerators
- ³He Systems
- Cryogenic accessories, flexible transfer lines and cryopumps

Custom engineered systems are designed and built to meet your exact requirements and include:

- Low photon flux, high radiation dewars
- Ultra high efficiency transfer system
- Testing apparatus for fountain effect characterization
- 2 K isothermal chamber for holography work

JANIS RESEARCH COMPANY, Inc.

2 Jewel Drive
Wilmington, MA 01887-0696
TEL: (508) 657-8750, FAX: (508) 658-0349
IN EUROPE: Cryophysics SA, Geneva TEL: 41 22 732 95 20

INSERT 14 ON REPLY CARD