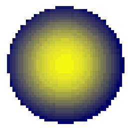
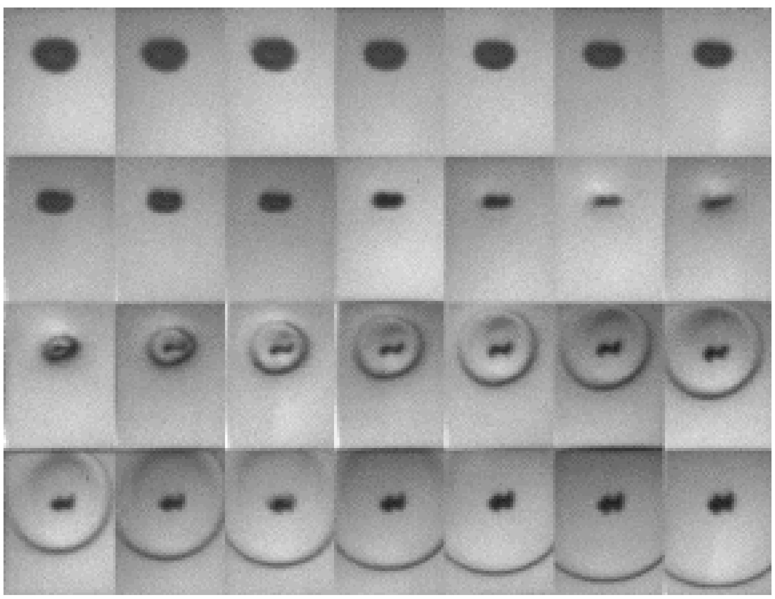
ESS 8, September 14-19, 2002 / Villasimius (Italy)

Information from Claudia L. Bianchi (e-mail: claudia.bianchi@unimi.it)

Cavitation Bubble Collapse
The Origin of Sonochemical Effects





The series is taken with 20 million frames/s. The black area in the centre is the collapsing bubble and the circularilly expanding halo starting in the third series is a shock wave.

W. Lauerborn et al., Ann. Phys. 4 (1995) 26

Sitemap - ESS

Sitemap - Sonochemistry

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Last modified on January, 2001.

European Society of Sonochemistry

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- ESS 6 Rostock (Germany), 1998
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ESS - Insight View

Join the ESS

The European Society of Sonochemistry is a non-profit organisation.The society and its members are interested in the promotion of the application of ultrasound in chemistry and related fields (e.g. materials science, medicine, biotechnology). Therefore, close contacts between sonochemists are maintained worldwide. Furthermore, the contact to chemists who have no or only some experience in sonochemistry is another main objective of the ESS. Thus, the bi-annual ESS meetings welcome not only sonochemists from all over the world but invite all chemists, physicists and other scientists interested in the application of ultrasound and sonochemistry. The ESS consists currently of 138 members from 28 countries of Europe, Northern America, Australia and Asia.

The Board

The ESS-Board currently consists of 11 members. The members have been elected by the last ESS General Assembly in Biarritz on May 17, 2000. The board

How to reach the board members ?			
Dr. G. Price **(President)**	School of Chemistry, University of Bath Bath BA2 7AY, U.K.	phone: (44) 1225 826504 fax: (44) 1225 826231	**chsgjp @bath.ac.uk**

Dr. D. Peters **(Treasurer)**	FB Chemie, Universität Rostock, Buchbinderstr. 9 D-18059 Rostock, Germany	phone: (49) 3814981836 fax: (49) 3814981819	
Prof. O. Abramov **(Eastern European Contact Person)**	Institut of General and Inorganic Chemistry, Leninsky Prospekt 31 Moscow, 117907, Russia	phone: (7) 0959557838 fax: (7) 0951338011	**abramov @ionchron.msc.ru**
Prof. T. Ando	Department of Chemistry, Shiga University of Medical Science, Seta Otsu, Shiga 520-21, Japan	phone: (81) 775482405 fax: (81) 775482108	**ando @sums.shiga-med.ac.jp**
Dr. W. Bonrath	F. Hoffmann-La Roche Ltd. Vitamins and Fine Chemicals Division CH-4070 Basel, Switzerland	phone: (41) 616886517 fax: (41) 616872117	**werner.bonrath @roche.com**
Prof. H. Delmas	INP, ENSIGC, Laboratoire de Génie Chimique F-31006 Toulouse Cedex, France	phone: (33) 0562252367 fax: (33)	**Henri.Delmas @ensigct.fr**

Prof. T.J. Mason	School of Chemistry, Coventry University, Priory Street Coventry, CV1 5FB, U. K.	phone: (44) 1203 838173 fax: (44) 1203 838173	**t.mason @coventry.ac.uk**
Prof. V. Ragaini	Department of Physical Chemistry, Univerita di Milano, Via Golgi 19 I-20133 Milano, Italy	phone: (39) 226603244 fax: (39) 270638129	**ragaini @rs14.csrsrc.mi. cnr.it**
Prof. C. Petrier	Université de Savoie, LCME, ESIGEC, Campus Scientifique de Savoie-Technolac F-73376 Le Bourget du Lac Cedex, France	phone: (33) 479758805 fax: (33) 479758804	**christian.petrier @univ-savoie.fr**
Prof. C. von Sonntag	MPI für Strahlenchemie P.O. Box 101365 D-45413 Mülheim an der Ruhr, Germany	phone: (+49) 2083063529 fax: (+49) 2083063591	**vonsonntag @mpi-muelheim. mpg.de**
Prof. K. Suslick	University of Illinois, School of Chemical Sciences, 505 S. Mathews Avenue Urbana, Illinois 61801, USA	phone: (+217) 3332794 fax:	**suslick @uiuc.edu**

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ESS - Membership

Join the ESS

The ESS welcomes people not only from Europe but also from all other countries around the world. You can become a personal member or a member as a representative of a company, organisation or other body. It implies compliance with the present bylaws and with the decisions taken by the General Assembly and the Board. Membership is subject to a fee proposed by the Board and approved by the General Assembly of the members.

The annual membership fee is currently **30 EURO**.

Download the **Membership Information Package** for all information concerning the membership. For application to the ESS membership fill in the included **Membership Application Form** and one of the **Membership Fee Payment Forms** and send both to the ESS.

Membership Information Package (Acrobat PDF)	Get Acrobat Reader

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Fee Payment

Membership fee payment is possible by **Bank Transfer** or - preferably - by **Credit Card** (**VISA or EUROCARD or MASTERCARD**). Payment by **Cheque** is not possible. for details see the Membership Information Package.

The ESS recommends strongly to pay by **Credit Card** because of cost and expenses concerns.

Credit Card	Please fill in the **Credit Card Payment Form** (**VISA, EUROCARD, MASTERCARD)** and mail it to the **ESS-Treasurer**. Please mark clearly the appropriate year(s) and the expiration date of your card.

Bank Transfer	Remit the membership fee by bank transfer to the ESS-account and mark clearly on your transfer form the appropriate year(s) and name. In addition, you are requested to download, fill in and send the **Bank Transfer Information Form** via e-mail or snail mail to the **ESS-Treasurer**. **We remind the members that they have to pay all bank expenses.**

Cheque	**NOT POSSIBLE !**

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ESS - Meetings

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Autrans (France), 1990	President of the Organising Commitee: **Prof. J. L. Luche**

ESS 2

Gargnano (Italy), 1991	President of the Organising Commitee: **Prof. V. Ragaini**

ESS 3

Figuera da Foz (Portugal), 1993	President of the Organising Commitee: **Prof. A. Campos Neves**

ESS 4

Blankenberge (Belgium), 1994	President of the Organising Commitee: **Prof. J. Reisse**

ESS 5

Cambridge (UK), July 7-11, 1996	President of the Organising Commitee: **Prof. T. Mason**

Plenary Lectures

J. Reisse	Homegeneous sonochemistry: a concept to be defined
A. A. Atchley	Single bubble sonoluminescence
W. Lauterborn	Cavitation bubble dynamics
J. L. Luche	A few questions about the sonochemistry of solutions
R. G. Compton	Sonoelectrochemistry; how ultrasound changes electrode processes
A. M. Wilhelm	Some studies in sonochemical engineering
K. S. Suslick	Sonochemical synthesis of protein microspheres
Feng Ruo	Sonochemistry in China
N. N. Amso	Current trends in therapeutic ultrasound
G. R. ter Haar	Focused ultrasound surgery: applications in cancer therapy
R. J. Siegel	Ultrasound thrombus dissolution
C. Kratzik	Transrectal high intensity focused ultrasound for prostatic disease

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ESS 6

Rostock-Warnemuende (Germany), May 10-14, 1998	President of the Organising Commitee: **Prof. R. Miethchen**

Plenary Lectures

M. Chanon	Electron Transfer Reactions
D. Walton	Sonochemical electrochemistry
C. von Sonntag	Aqueous sonochemistry: free radicals in two phases
B. Gompf	Single bubble sonoluminescence
T. Matula	Sonoluminescence
T. Ando	Mechanisms of sonochemical excitation in organic reactions
F. Luzzio	Applications of ultrasound in alkaloid synthesis
G. Price	Control of polymer structure and properties using power ultrasound

---

ESS 7

Biarritz-Guéthary (France), May 14-18, 2000	President of the Organising Commitee: **Prof. H. Delmas, Prof. A. M. Wilhelm**

http://www.univ-inpt.fr/~ESS7/"

Plenary Lectures

M. Mingos	Chemistry under extreme conditions

A. Szeri	Fundamentals of heat and mass transfer in sonoluminescence and sonochemistry
M. S. F. Lie Ken Jie	Lipidic sonochemistry
F. Grieser	The role of surface chemistry in sonoluminescence and sonochemistry
M. R. Hoffmann	Application of ultrasonic irradiation for the degradation of chemical contaminants
A. Thiem	Application of ultrasound to enhance biological degradation processes
C. Horst	Sonochemical engineering of solid-liquid processes

ESS 8

Villasimius (Italy), September 14-19, 2002	President of the Organising Commitee: **Prof. V. Ragaini**

Information from Claudia L. Bianchi"

http://users.unimi.it/ess8/ess8.html"

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ESS - News and Information

Headlines

SonoResearch Groups	• **Webpages of research groups that are working in sonochemistry, sonoluminescence and the application of ultrasound**
SonoEquipment Supplier	• **Webpages of suppliers of sonochemical and ultrasonic equipment**
SonoResearch Topics	• **Webpages of research topics on sonochemistry, sonoluminescence and the application of ultrasound**
SonoLiterature	• **Literature, books and journals on sonochemistry and the application of ultrasound**
COST	• **COST Chemistry Action D6** • **COST Chemistry Action D10**
SonoMeeting Abstracts	• **Sonochemistry Information Day of the DECHEMA** • **9th Meeting of the Japan Society of Sonochemistry** • **Innovative Energy Sources in Chemical Engineering**
SonoJobs	• **Vacancies for M.Sc., Ph.D., Post-doc**

SonoLinks

- **Other pages on sonochemistry, ultrasound and acoustics**

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Sonochemistry

Sonochemistry - Introduction

- What is Sonochemistry ?
- Acoustic Cavitation: Fundamentals and Effects
- Applications of Ultrasound in Chemistry, Life and Material Sciences
- Sonoluminescence
- Historical Milestones from the Early Years of Sonochemistry

Sonochemistry - Images

- Cavitation Images and Movies
- Cavitation Effects
- Sonochemistry Images and Figures
- Sonoluminescence Equipment and Images
- Ultrasonic Equipment and Applications

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- Meeting Calendar 2000-2002

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Sonochemistry - Introduction

Fundamentals

What is Sonochemistry ?

Sonochemistry is the application of ultrasound to chemical reactions and processes. Ultrasound is the part of the sonic spectrum which ranges from about 20 kHz to 10 MHz and can be roughly subdivided in three main regions: low frequency, high power ultrasound (20-100 kHz), high frequency, medium power ultrasound (100 kHz-1 MHz), and high frequency, low power ultrasound (1-10 MHz). The range from 20 kHz to around 1 MHz is used in sonochemistry wheras frequencies far above 1 MHz are used as medical and diagnostic ultrasound.

Acoustic Cavitation

The origin of sonochemical effects in liquids is the phenomenon of acoustic cavitation. The term cavitation comes from the latin word *cavus* = cavity. Acoustical energy is mechanical energy i.e. it is not absorbed by molecules. Ultrasound is transmitted through a medium via pressure waves by inducing vibrational motion of the molecules which alternately compress and stretch the molecular structure of the medium due to a time-varying pressure. Therefore, the distance among the molecules vary as the molecules oscillate around their mean position. If the intensity of ultrasound in a liquid is increased, a point is reached at which the intramolecular forces are not able to hold the molecular structure intact. Consequently, it breaks down and a cavity is formed. This cavity is called cavitation bubble as this process is called cavitation and the point where it starts cavitation threshold. A bubble responds to the sound field in the liquid by expanding and contracting, i.e. it is excited by a time-varying pressure.Two forms of cavitation are known: stable and transient. Stable cavitation means that the bubbles oscillate around their equilibrium position over several refraction/ compression cycles. While transient cavitation, the bubbles grow over one (sometimes two or three) acoustic cycles to double their initial size and finally collapse violently.

The size, life time and fate of a cavitation bubble depend on the following parameters: frequency, intensity (acoustic pressure), solvent, bubbled gas, external parameter (temperature, pressure). However, it should be noted that there is often no simple relationship.

For some images on the cavitational collapse see the special page on **images of sonochemistry and sonoluminescence**.

Physical Effects

There are three different theories about cavitation - the hot-spot, the electrical and the plasma theory. The most popular one is the hot spot theory. Thus, it has been experimentally shown that the cavitational collapse creates drastic conditions inside the medium for an extremely short time: temperatures of 2000-5000 K and pressures up to 1800 atm inside the collapsing cavity. A remarkable event during the cavitation collapse is the emission light under certain conditions (**sonoluminescence**). Furthermore, the collapse causes a couple of strong physical effects outside the bubble: shear forces, jets and shock waves. Thus, there are basically two groups of effects: radical and mechanical effects. These cavitation-induced effects can cause physical, chemical, and biological effects. Thus, ultrasound has been found applications in chemistry, materials and life sciences as well as medicine.

Chemical Effects

There is no doubt that the origin of sonochemical effects is cavitation. There a three possible reaction sides of a collapsing bubble: the cavity interior, the bubble vicinity and the bulk solution. Due to the extreme conditions inside the medium and other cavitation effects the following effects depending on the sonication conditions have been found :

radical effects

- ligand-metal bond cleavage in transition metal complexes to give coordinatively unsaturated species or modified complexes as well as complete strip off of ligands to produce amorphous metals
- disrupture of the solvent structure altering the solvation of reactants
- sonolysis of molecules (homolytic fragmentation to radicals, rupture of polymers, generation of excited states, cell disrupture)

mechanical effects

- mechanical effects by cavity collapse onto metals and solids (shear forces, jets and shock waves resulting in rapid mass transfer, surface cleaning, particle size reduction

and metal activation), modification of the properties of solid particles
- influence on electrochemical processes
- effects in liquid-liquid systems (improved mass transfer, emulsification, increase of the effect of phase transfer catalysts or even their replacement
- effects in gas-liquid systems (degassing of liquids or melts, atomisation of liquids in air, thin film preparation)
- single electron transfer (SET) steps in chemical reactions may be accelerated and if an ionic and an electron transfer pathway are possible the latter seems to be preferred ("sonochemical switching")

Ultrasound in Chemistry, Materials and Life Sciences

There are a wide range of applications of ultrasound in these fields. Therefore, only a selection of important and interesting examples and effects are given in the following to show the far range of possible applications and just to give an impression what ultrasound/ sonochemistry means.

Applications in Chemistry

The following beneficial sonochemical effects onto chemical reactions and processes can be observed :

- decrease of reaction time and/or increase of yield
- use of less forcing conditions e.g. lower reaction temperature
- possible switching of reaction pathway
- use of less or avoidance of phase transfer catalysts
- degassing forces reactions with gaseous products
- use of crude or technical reagents
- activation of metals and solids
- reduction of any induction period
- enhancement of the reactivity of reagents or catalysts

  generation of useful reactive species

Applications in Materials Science

There are some obstacles if a reaction should proceed between a solid and a liquid (or in a liquid dissolved) reactant in a heterogeneous system: the small surface area of a bulk solid, the solid surface may be coated by oxide layers or impurities, species have to diffuse to and away from the solid surface, deposition of products may inhibit further reactions. Applications of ultrasound to such systems are:

- preparation of activated metals by reduction of metal salts (e.g. reduction with Li in THF to RIEKE-type powders or with formaldehyde to Pd or Pt), generation of activated metals by sonication, precipitation of metal (Cr, Mn, Co) oxide catalysts, impregnation of metals or metal halides on supports
- preparation of activated metal solutions (e.g. colloidal alkali metal solutions, suspension of Mg or Hg), preparation of organometallic compounds from main group or transition metals, sonochemical reactions involving metals via in situ generated organoelement species, reactions involving non-metallic solids
- crystallisation and precipitation of metals, alloys, zeolithes and other solids, agglomeration of crystals, degassing of melts, spray pyrolysis to form thin films or fine particles, treatment of solid surfaces, dispersion of solids, preparation of colloids (Ag, Au, Q-sized CdS)
- ultrasonic sieving, filtration and micromanipulation (transportation, concentration, fractionation) of small particles, intercalation of guest molecules into host inorganic layered solids, ultrasonic-aided development in advanced lithography, electroless plating, wetting and impregnation

- sonochemistry of polymers consisting of three main fields: the degradation and modification of polymers, the ultrasonically assisted synthesis of polymers and the determination of the polymer structure
- sonolysis of organic pollutants in water has become a developing field of research in environmental technology

- ultrasonic plastic and metal welding, machining, ultrasonic soldering
- sonocleaning
- spraying, metal welding, machining and surface hardening

  ultrasound food technology (fields of interest: mixing, blending, extraction, crystallisation, foam destruction, particle/aerosol precipitation, oxidation)

Ultrasound in Life Sciences and Medicine

Firstly, applications without any destruction or damage on living tissues :

- disturbing of dermal cell membranes used for drug delivery (sonophoresis)
- ultrasonic imaging
- ultrasound nmr
- diagnostic ultrasound
- dental scaling and ultrasonic nebulizers in medical therapy
- enzyme activation

Secondly, ultrasound caused damage on living tissues :

- cell disrupture (extraction of plant substances, disinfecting, enzyme deactivation)
- therapeutic ultrasound, i.e. induction of thermolysis in tissues (cancer treatment)
-

Thirdly, sonochemical preparation of biomaterials

- air-filled protein microbubbles
- nonaqueous liquid-filled protein microcapsules

Sonoluminescence

There are two forms of sonoluminescence: single-bubble SL and multi-bubble SL. Sonoluminescence was first discovered in 1930s. But, only in the late 1980's an intensive research started. The first researchers saw multiple-bubble sonoluminescence (MBSL), i.e. the glow from many bubbles of air in water. Since the glow for these bubbles is so faint, it must be viewed in a darkened room. Single-bubble sonoluminescence (SBSL), however, can be seen in a lighted room. 1990, however, was the first year that SBSL was observed, discovered by Gaitan and Crum, who after extensive research, found just the right conditions for SBSL to occur. To create SBSL, a single bubble of gas must be placed in the liquid. This can be done by injecting a bubble of air with a syringe, but researchers today use more elaborate setups. After being injected into the center of a cylindrical flask, the bubble would normally rise, but it is held in place by the force of the sound waves bombarding it. Around 110 decibels are required for sonoluminescence, and while this volume might seem high enough to cause deafness, the frequency of the sound is also important for SL, and it lies just beyond the range of human hearing. Putterman and his group discovered that the light flashes have an upper bound of 50 picoseconds (ps), and these flashes come out with incredible regularity.

For a detailed introduction look on **other SL-websites**.

For some images on SL see the special page on **images of sonochemistry and sonoluminescence**.

Historical Milestones

1867	Early observations of cavitation (TOMLINSON, GERNEZ)
1880	Discovery of the piezoelectric effect
1883	Earliest ultrasonic transducer by GALTON
1894	Cavitation as phenomenon recognized and investigated on propeller blades of HMS Daring (THORNYCROFT and BARVABY, Minutes of Proceedings of the Institution of Civil Engineers **122** (1895) 51)
1915-17	Pioneering work on ultrasonic acoustics by LANGEVIN

1917	First mathematical model for cavitational collapse predicting enormous local temperatures and pressures (RAYLEIGH)
1927	First paper on chemical effects of ultrasound published (RICHARDS and LOOMIS, J. Am. Chem. Soc. **49** (1927) 3086)
1933-35	Observation of sonoluminescence effects
1933	Reports on the reduction in the viscosity of polymer solutions by ultrasound
1943	First Patent on cleaning by ultrasound (German Pat. 733.470)
1944	First patent on emulsification by ultrasound (Swiss Pat. 394.390)
1950s	Intensification of cavitation and ultrasound research, increasing number of applications using ultrasound
1950	Effect of ultrasound on chemical reactions involving metals (RENAUD, Bull. Soc. Chim. Fr. (1950) 1044)
1950	Hot spot model (NOLTINGK and NEPPIRAS)
1953	First review on the effects of ultrasound (BARNARTT, Quart. Rev. **7** (1953) 84)
1963	Introduction of plastic ultrasonic welding
1964	First monograph on physical, chemical and biological effects of ultrasound (ELPINER)
1970s	Renaissance of sonochemistry research
since 1980	Growing research on sonochemical effects
1986	First ever international meeting on sonochemistry
1990	Foundation of the European Society of Sonochemistry and ESS 1 Meeting

Sonochemistry - Images

Cavitation	Sonoluminescence	Equipment and Applications

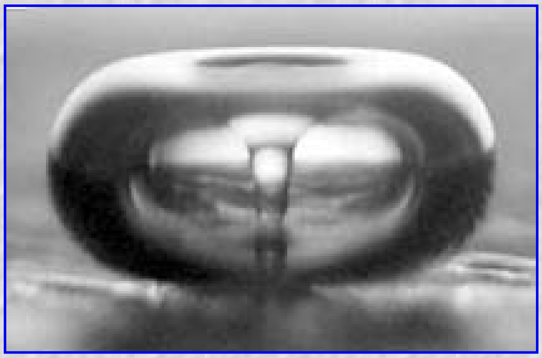
The image and movie files are taken from different web sites, collected on this server and rearranged on this page. Click on an the individual image to see it in full size.

Be patient while loading the images (about 5 Mbyte) !

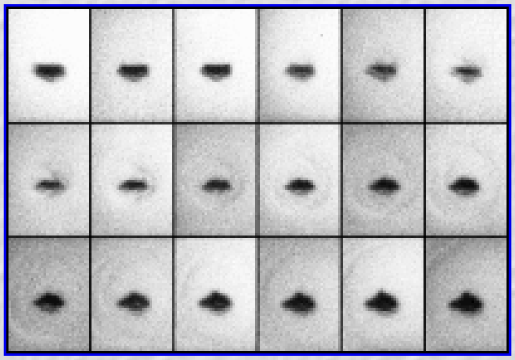
Moreover, the corresponding URL is given to see the images in the original context and for import additional information. There you will also find the original author and how to contact him/her (N.B. It may be happen that the original URL changes and expires).

Cavitation

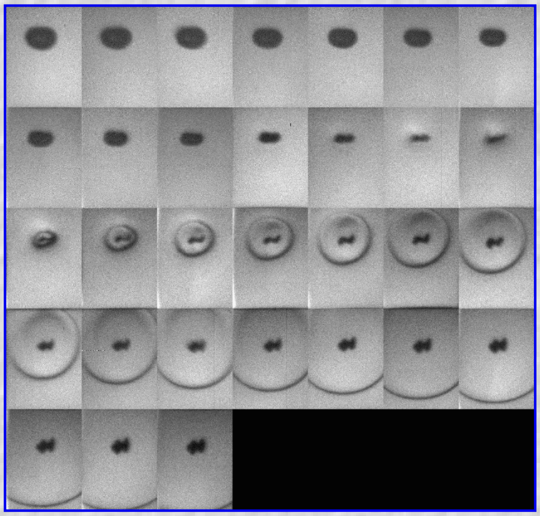
Cavitation Bubbles



source: http://pluto.apl.washington.edu/harlett2/artgwww/acoustic/medical/litho.html

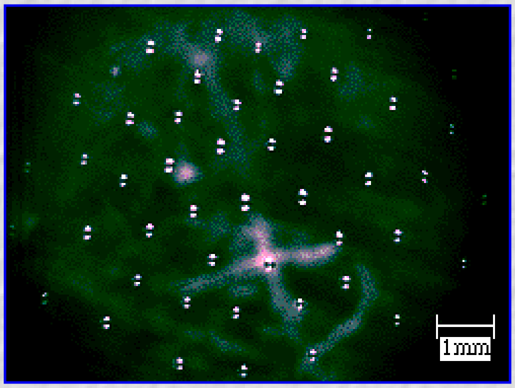


source: http://www.physik3.gwdg.de/~ohl/cavitation.html (Link to image does not longer exist)



source: http://www.physik3.gwdg.de/~ohl/cavitation.html

The hexagonal pattern on the following image was made by charging drops and levitating them in a strong electric field. This system has been used to study the evaporation of dense sprays and will be used in combustion studies:



source: http://www.eng.yale.edu/faculty/vita/apfel-data/apfel-result.html

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There are also some movies on the subject:

Movie comparing a rendered bubble and photographs done with 20 million frames per second

source: http://www.physik3.gwdg.de/~rgeisle/nld/sl.html

Movie of an aspherically collapsing bubble

source: http://www.physik3.gwdg.de/~rgeisle/nld/sl.html

Periodic radial oscillation of a SL bubble

source: http://www.physik3.gwdg.de/~rgeisle/nld/sl.html

Shock wave emmitted by a SL bubble

source: http://www.physik3.gwdg.de/~rgeisle/nld/sl.html

Integrated light of a multibubble system (at the upper right corner you see a clock, which shows the phase of gating in relation to the excitation)

source: http://www.physik3.gwdg.de/~ohl/sonoluminescence.html

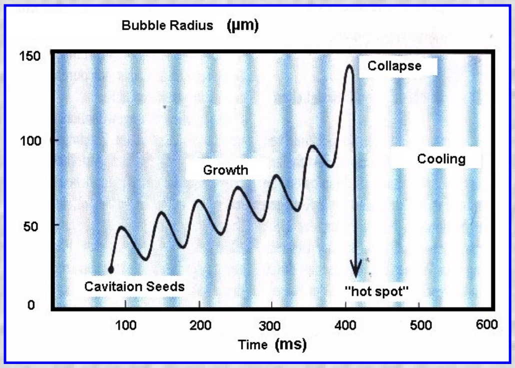
Non-linear oscillation of acoustically levitated drops in a sound field

source: http://www.eng.yale.edu/faculty/vita/apfel.html

Stroboscopic images of single collapsing bubble

source: K. Suslick / T. Matula http://www.scs.uiuc.edu/~suslick/execsummsono.html

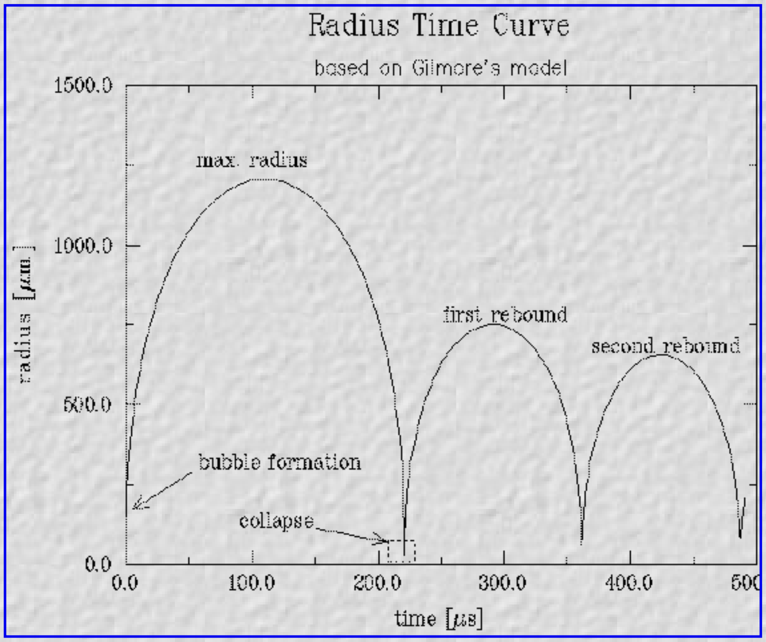
Scheme of a collapsing cavitation bubble:



source: Keneth Suslick

see also: *Spektrum der Wissenschaft*, Special edition "Chemistry", 1995, pp. 96-98

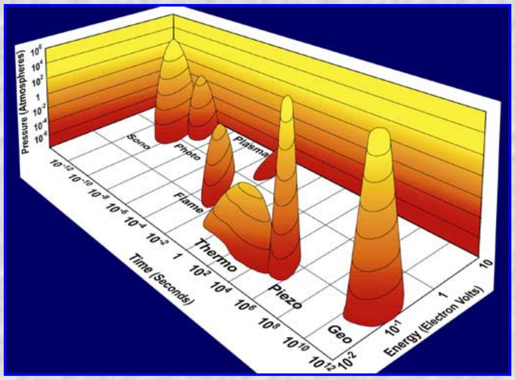
Radius/Time Curve according to the GILMORE model:



source: http://www.physik3.gwdg.de/~ohl/cavitation.html

Cavitation Effects

Chemistry under extreme condition - the interaction of energy and matter:



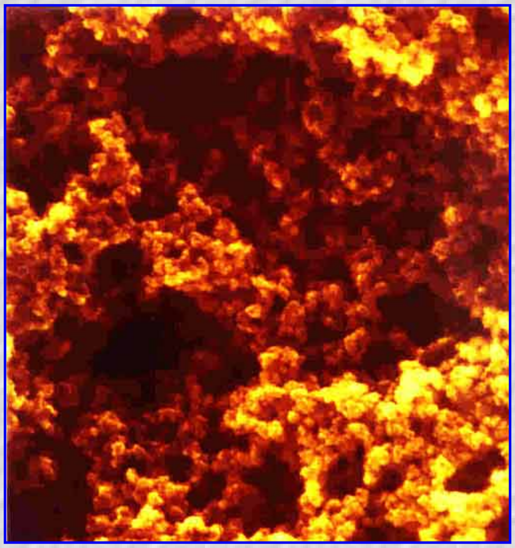
source: http://www.scs.uiuc.edu/~suslick/execsummsono.html

see also: *Spektrum der Wissenschaft*, Special edition "Chemistry", 1995, pp. 96-98

Bubble collapse near an extended surface is distorted and leads to a shaped-charge effect with liquid jet impacts at >100m/s:

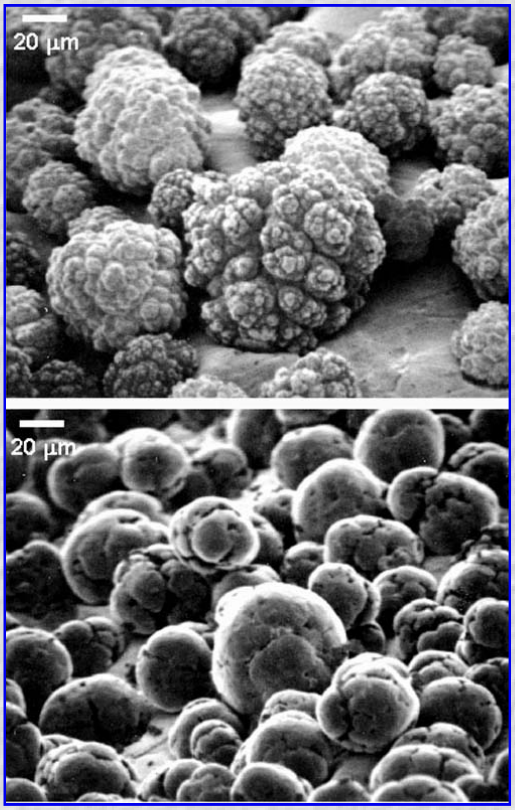
source: http://www.scs.uiuc.edu/~suslick/execsummsono.html

Scanning electron micrograph of amorphous nanostructured iron powder produced from the ultrasonic irradiation of Fe(CO)5. Particles making up this porous agglomerate are 10 to 20 nm in diameter:



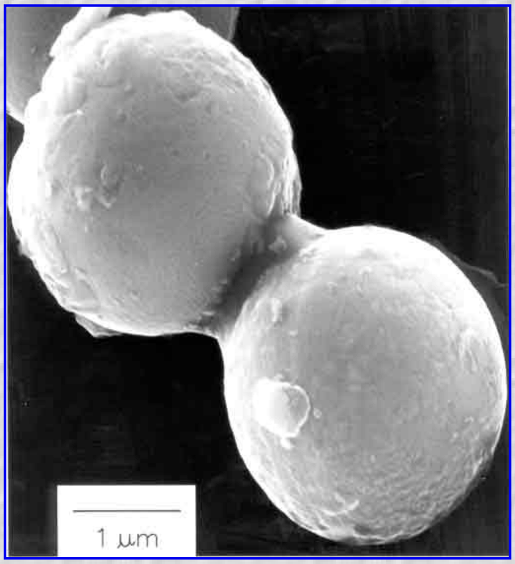
source: http://www.scs.uiuc.edu/~suslick/execsummsono.html

The effect of ultrasonic irradiation on the surface morphology and particle size of Ni powder. Upper image is before ultrasound and lower is after irradiation of a slurry in decane. High-velocity interparticle collisions caused by ultrasonic irradiation of slurries are responsible for the smoothing and removal of passivating oxide coating



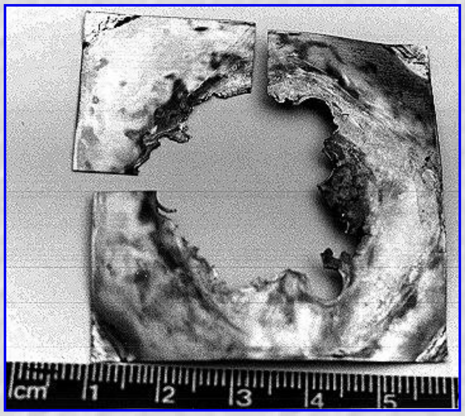
source: http://www.scs.uiuc.edu/~suslick/execsummsono.html

Scanning electron micrograph of 5 m m diameter Zn powder. Neck formation from localized melting is caused by high-velocity interparticle collisions:



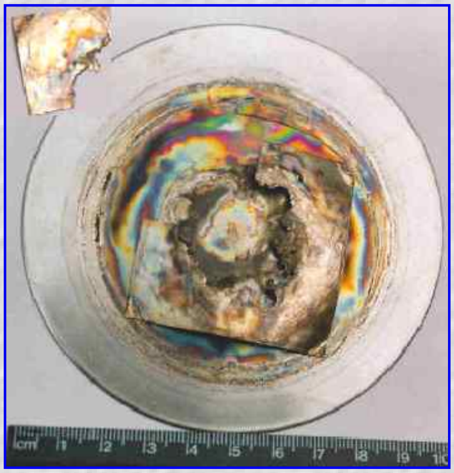
source: http://www.scs.uiuc.edu/~suslick/execsummsono.html

Cavitation damage on a palladium metal foil treated in a sonofusion reactor chamber:



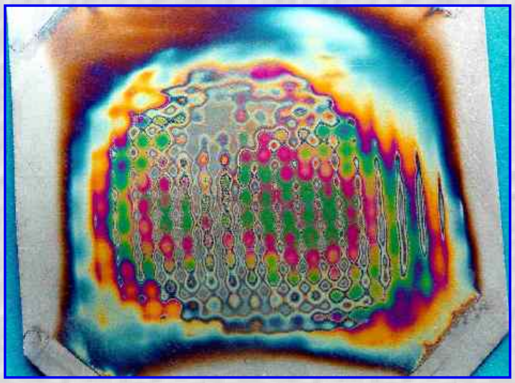
source: http://rsrch.com/saturna/sonofusion.html (Link does not longer exist)

Melted palladium target (50mm x 50mm x 0.1mm):



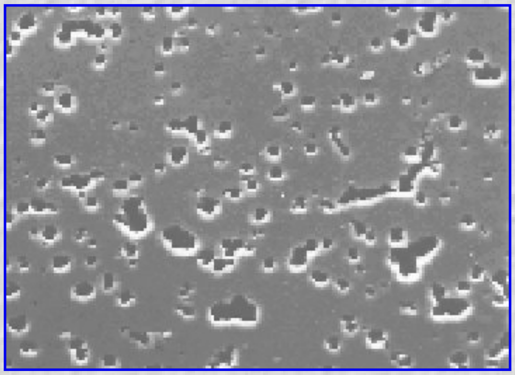
source: http://rsrch.com/saturna/sonofusion.html (Link does not longer exist)

True color photograph of a Titanium foil 5cm by 5cm as seen upon removal from an sonoreactor. The pattern reveals acoustic standing wave resonance in this foil which also produced a large amount of heating:



source: http://rsrch.com/saturna/sonofusion.htmlsource: http://rsrch.com/saturna/sonofusion.html (Link does not longer exist)

Scanning electron micrograph of a glassy carbon surface after sonication in water for 5 minutes:



source: http://www.chem.duke.edu/~coury/sonic2.html (URL does no longer exist)

A scanning electron micrograph of a brass plate after a few shocks. Notice the craters that are formed. These are indicative of damage by high speed jets caused by collapsing cavitation bubbles:

source: http://pluto.apl.washington.edu/harlett2/artgwww/acoustic/medical/litho.html

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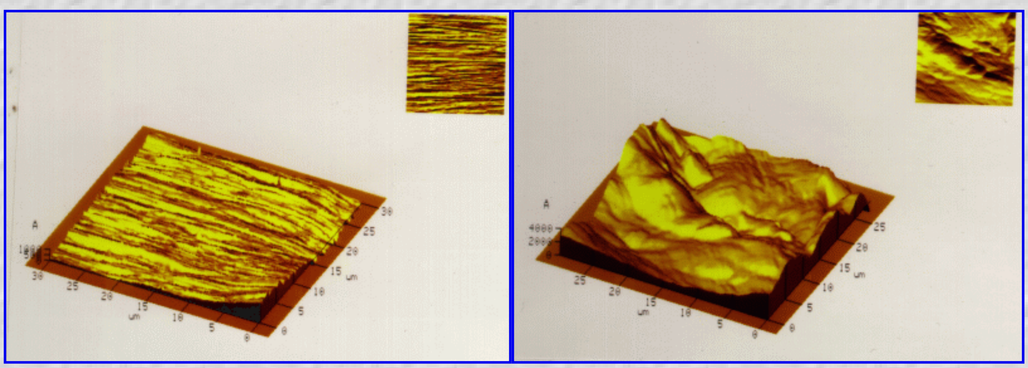
Images of a polished platinum electrode surface before being exposed to ultrasound (above) and the same electrode after being exposed to full power ultrasound from a 20kHz horn for 600 seconds (bottom):



source: http://physchem.ox.ac.uk:8000/research/sono/surffx.shtml

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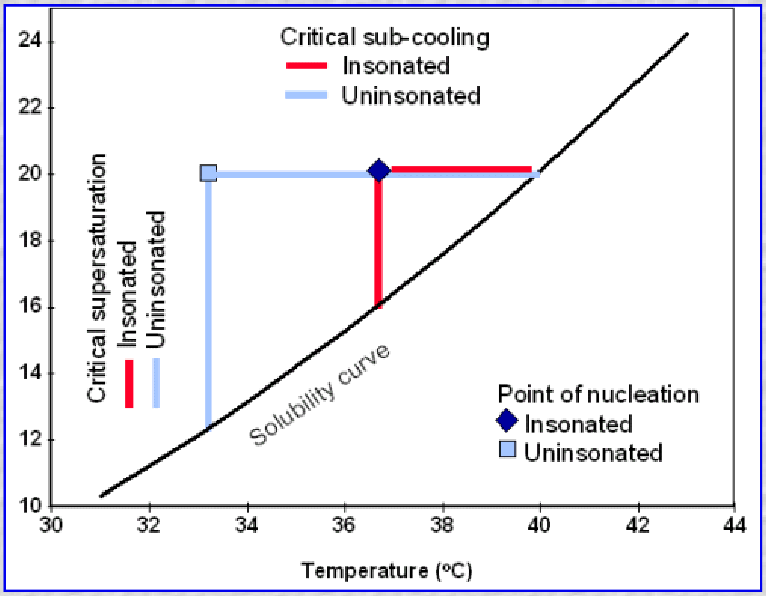
Particle size reduction by ultrasound (left - before sonication, right - after sonication):

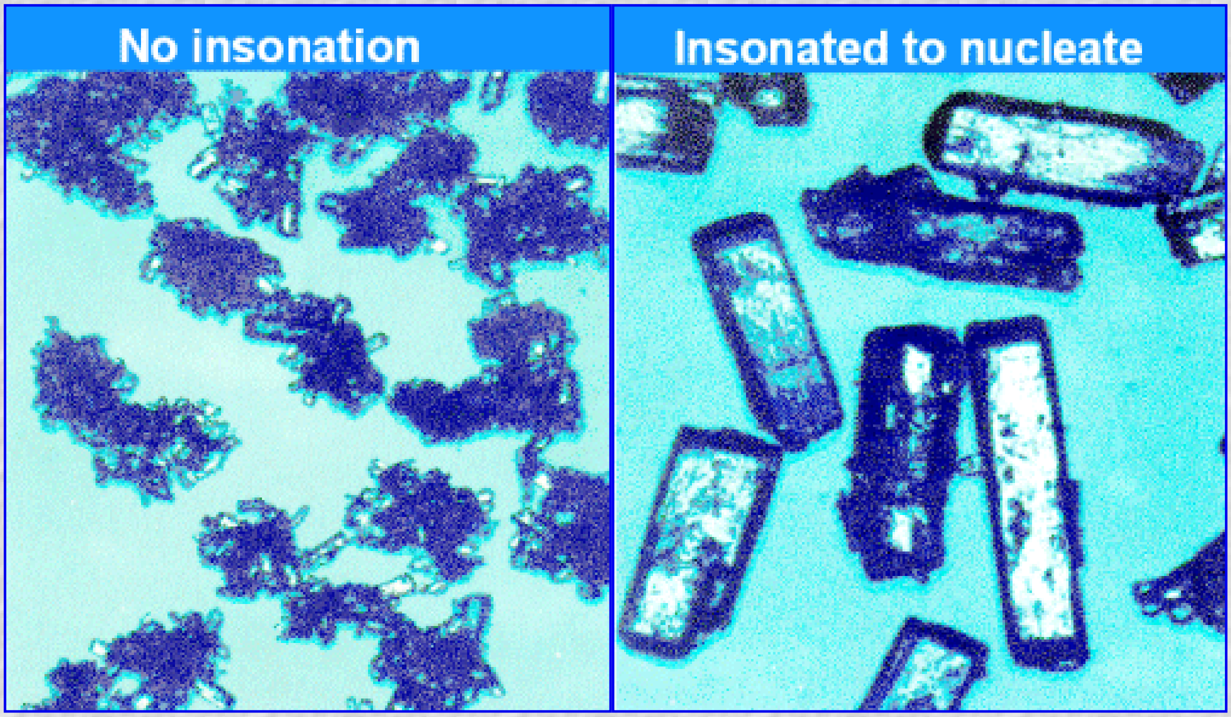
source: http://www.aeat.co.uk/sono/ (Link does not longer exist)

Cavitation events serve as nuclei for new crystals to form and grow. At high intensities ultrasound can be used instead of seed crystals, and/or to start nucleation at a lesser degree of supersaturation than would normally be the case:



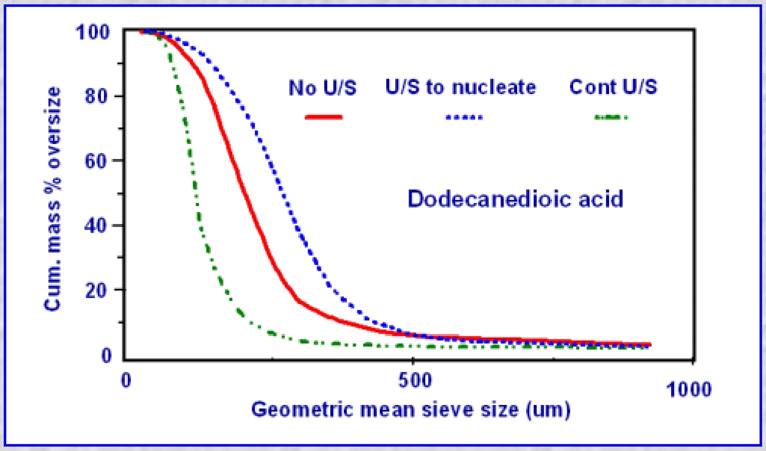
souce: http://www.aeat.com/sono/

Effect of ultrasound on the habit and perfection of sorbitol hexaacetate crystals:



souce: http://www.aeat.com/sono/

Control of the crystal size distribution of dodecanedioic acid. The solid line shows the base case where no ultrasound was used; the dashed line shows where ultrasound was used to nucleate the solution; and the chain linked line shows where ultrasound was used continuously throughout the crystallization. Insonation to nucleate shows a marked increase in the mean crystal size, whereas continuous insonation has dramatically reduced the mean size:

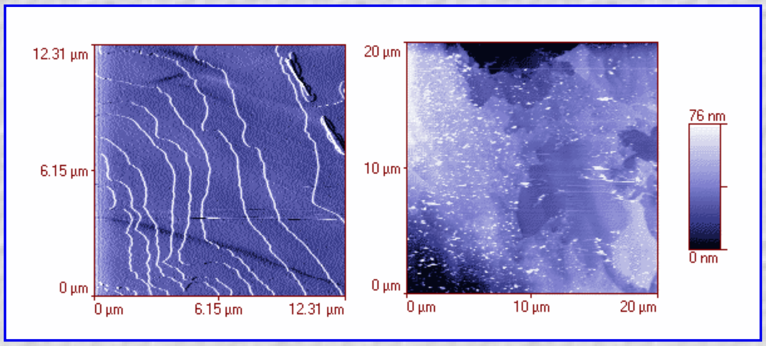


souce: http://www.aeat.com/sono/

Images of p-chloranil single crystals before dissolution and after dissolution under silent and sonicated conditions:

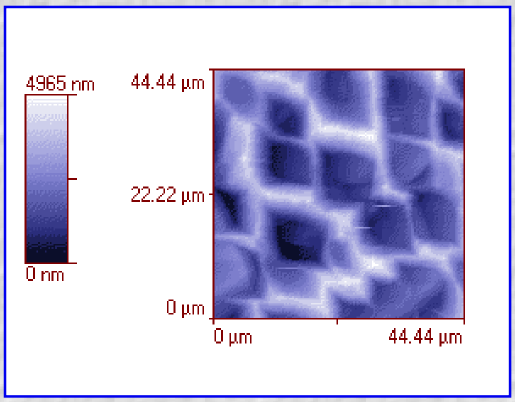
Figure 1. Atomic force microscopy image of a single crystal (001 face) recorded in air before any dissolution indicating that the crystals before dissolution are very smooth; the surfaces show

steps of height ca. 10 A and multiples there-of. This value approximates to the unit cell dimension. (left) and image of a single crystal (001 face) recorded in air after dissolution under an aqueous solution of 0.2M KCl indicating that after dissolution some surface roughening is observed (right):



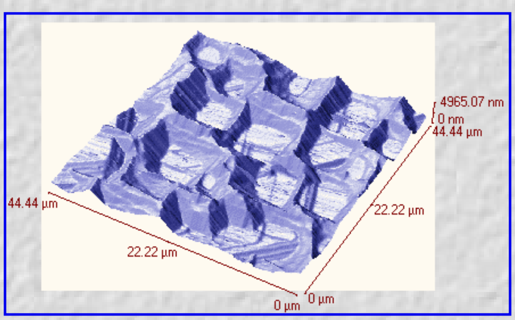
source: http://physchem.ox.ac.uk:8000/research/sono/emma.shtml

Figure 2. Atomic force microscopy image of a single crystal (001 face) recorded in air after dissolution under an aqueous solution of 0.2M KCl/15mM KOH for a period of 5 minutes in the presence of power ultrasound leading to the formation of pits as deep as 5 mm:



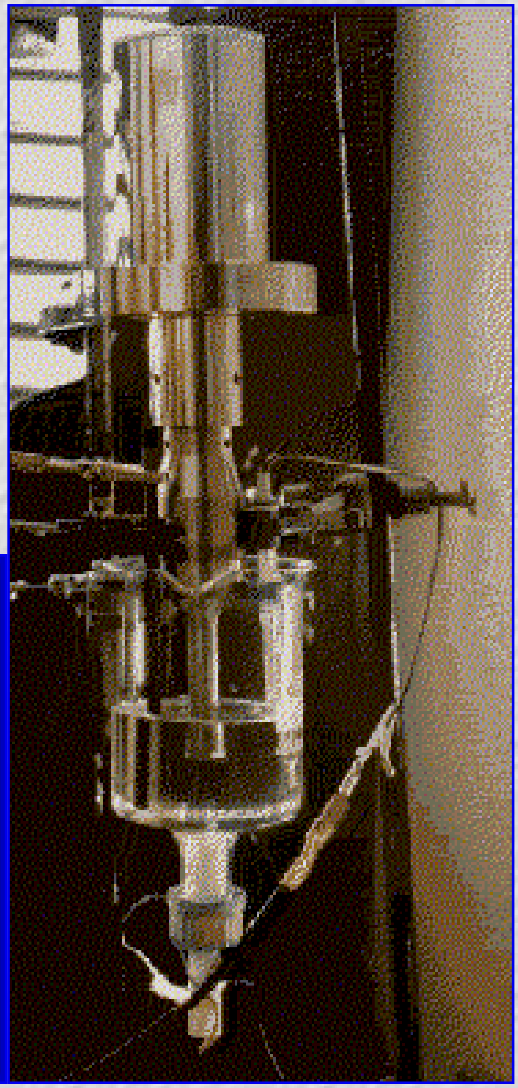
source: http://physchem.ox.ac.uk:8000/research/sono/emma.shtml

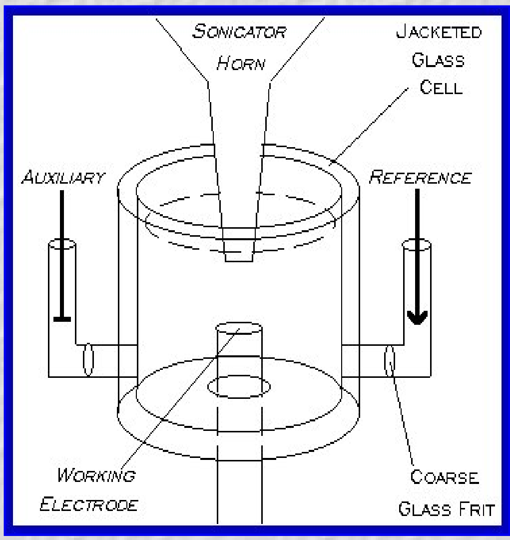
Figure 3. Three dimensional plot of an atomic force microscopy image of a single crystal (001 face) recorded in air after dissolution under an aqueous solution of 0.2M KCl/15mM KOH and subjection to a period of 5 minutes of ultrasound. The heavy pitting seen suggest that transient bubble collapse plays a significant role in the interfacial dissolution mechanism in the presence of ultrasound:



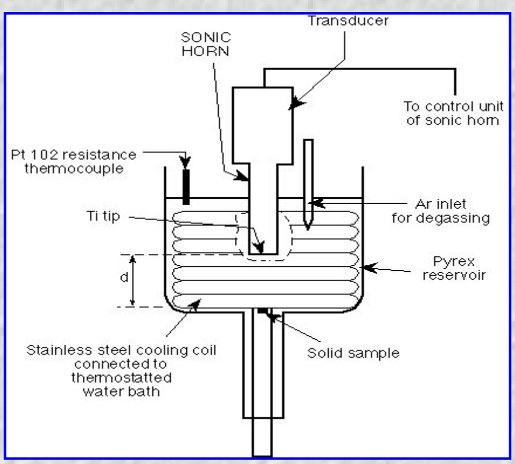
source: http://physchem.ox.ac.uk:8000/research/sono/emma.shtml

Sonoelectrochemical cells:



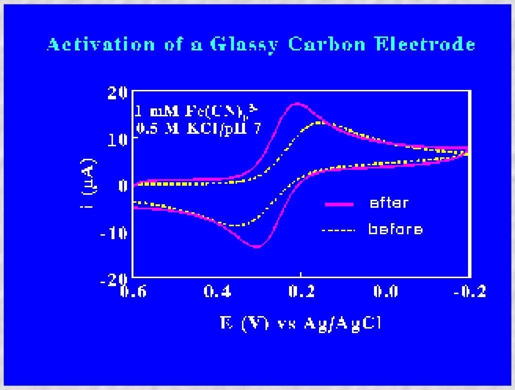


source: http://physchem.ox.ac.uk:8000/research/sono/emma.shtml



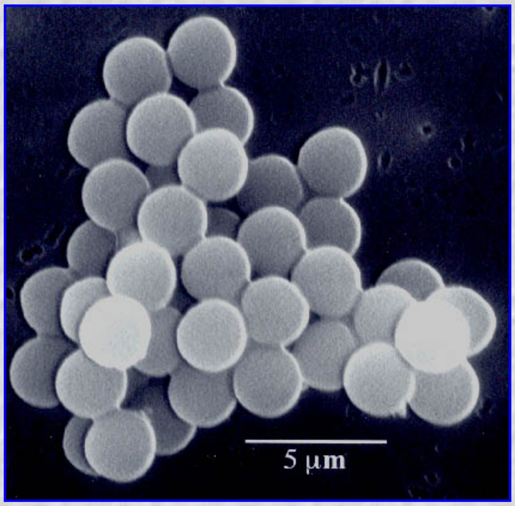
source: http://www.bk.psu.edu/faculty/cooper/ (URL does no longer exist)

If electrodes were sonicated in relatively non-volatile organic solvents (e.g., dioxane), they were rendered highly active and showed faster electron transfer kinetics for various redox couples when placed in aqueous solutions. This can be seen in the figure below, since the peak splitting in the cyclic voltammogram decreases markedly after sonication:



source: http://www.chem.duke.edu/~coury/sonic2.html (URL does no longer exist)

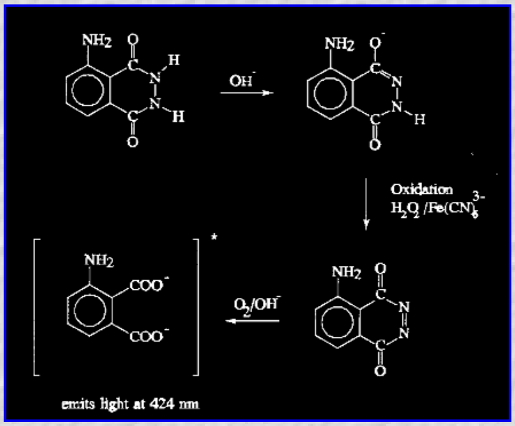
Scanning electron micrograph of sonochemically synthesized hemoglobin microspheres:



source: http://www.scs.uiuc.edu/~suslick/execsummsono.html

Ultrasound-Induced Chemoluminescence

Chemoluminescence generated by acoustic cavitation in alkaline solutions of water and luminol based on the following chemical reaction (ultrasound-induced by generating hydroxyl radicals):



source: http://physchem.ox.ac.uk:8000/research/sono/intro.shtml

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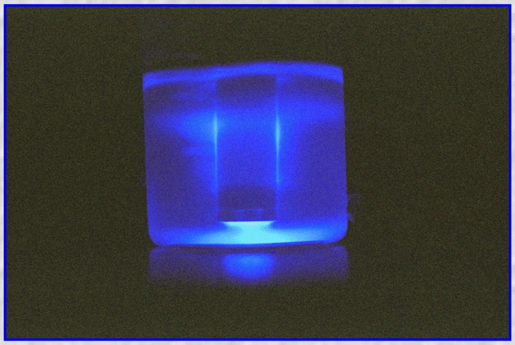
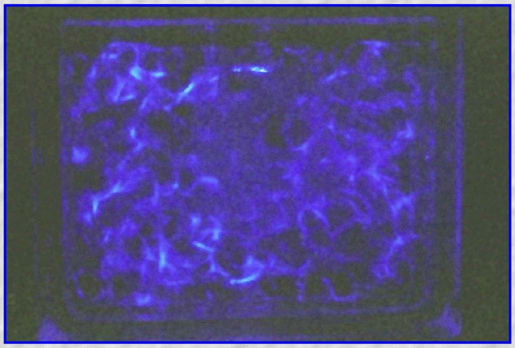
A 20 kHz high-power acoustic horn produces a small region of intense cavitation near the horn's tip (luminol-chemoluminescence generated by acoustic cavitation)::



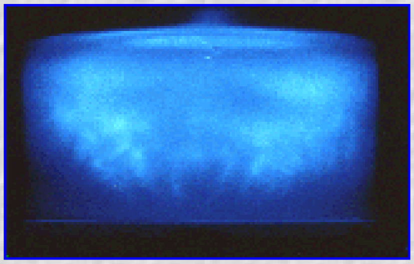
source: http://qvack.lanl.gov/Ultrasonics/ULTRASONICS.HTML (URL does no longer exist)

A single transducer produces a more diffuse, uniform cloud of cavitation surrounding the source (located in the top middle of the picture) at 20 kHz (luminol-chemoluminescence generated by acoustic cavitation):



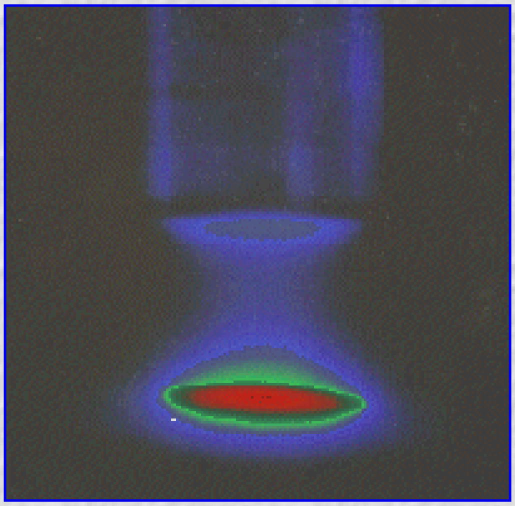
source: http://qvack.lanl.gov/Ultrasonics/ULTRASONICS.HTML (URL does no longer exist)

High frequency ultrasound cavitation (luminol-chemoluminescence generated by acoustic cavitation):



source: http://qvack.lanl.gov/Ultrasonics/ULTRASONICS.HTML (URL does no longer exist)

Ultrasonic horn cavitation image based on luminol-based chemoluminescence by ultrasound:



source: http://www.bk.psu.edu/faculty/cooper/ultrasnd.html

source: http://pluto.apl.washington.edu/harlett2/artgwww/acoustic/sound.html

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source: http://rsrch.com/saturna/sonofusion.html (Link does not longer exist))

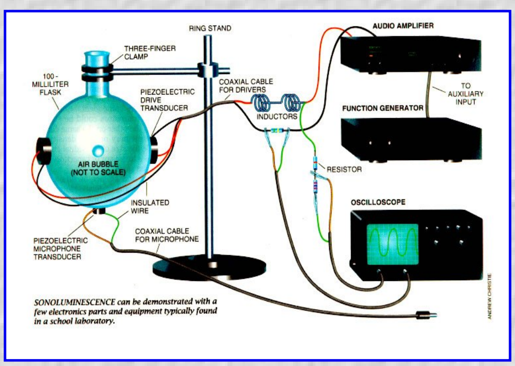
Chemoluminescence (in solutions of water and luminol) in a sonoelectrochemical cell. Stimulation by both a negative electrode potential as well as by radical species generated by cavitation induces the effect. The blue glow is easily visible throughout the whole cell and is especially bright in the region close to the electrode surface and close to the horn probe:

source: http://physchem.ox.ac.uk:8000/research/sono/intro.shtml

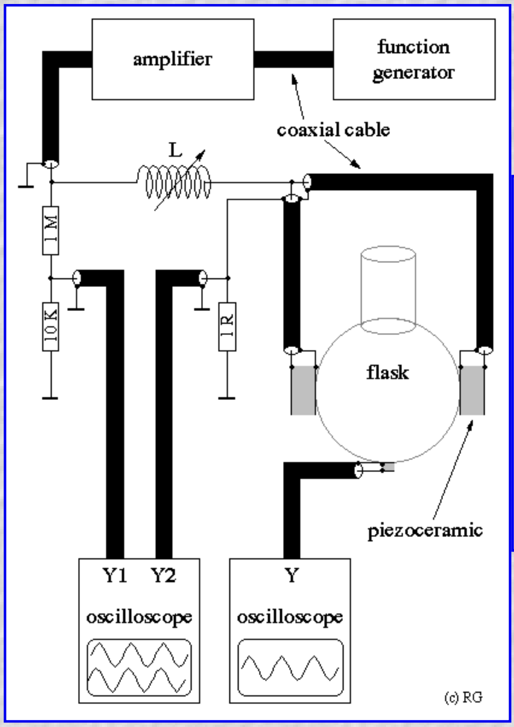
Sonoluminescence

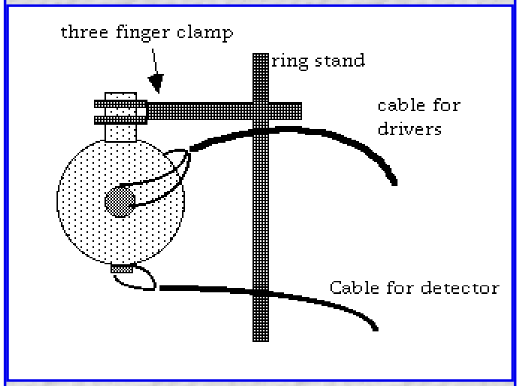
Experimental

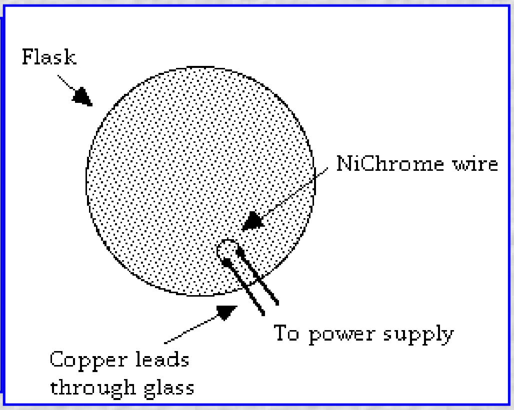
Experimental Scheme for Single bubble Sonoluminescence (SBL) and representation of the stable single bubble sonoluminescence system:



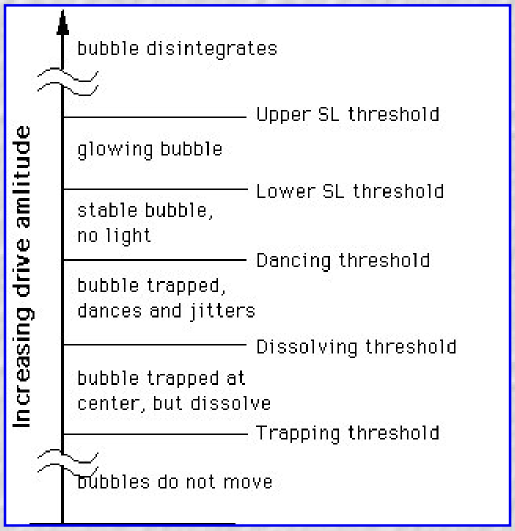
source: http://ne43.ne.uiuc.edu/ans/sonolum.html (URL does no longer exist) see also: *Scientific American*, vol. 272, Feb. 1995, pp. 96-98





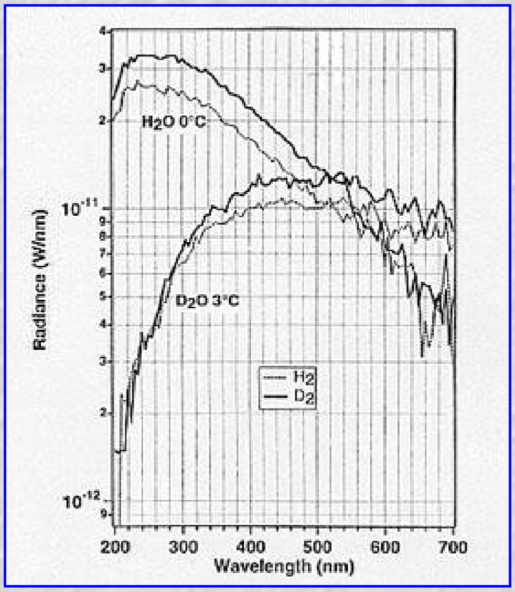


source: http://www.physics.ucla.edu/~hiller/sl/ (URL does no longer exist)

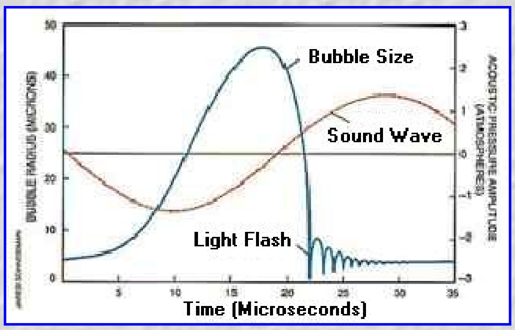


source: http://www.physics.ucla.edu/~hiller/sl/ (URL does no longer exist)

Sonoluminescence spectra in water and heavy water in the presence of H2 and D2:



source:http://ne43.ne.uiuc.edu/ans/sonolum.html (URL does no longer exist)



source: http://rsrch.com/saturna/sonofusion.html (Link does not longer exist)

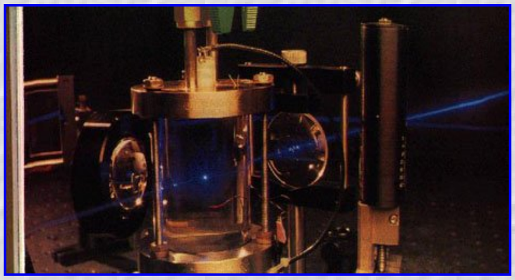
Single bubble Sonoluminescence (SBL):

source: http://webphysics.davidson.edu/andyo/exp/sono/constr.htm (URL does no longer exist)

SL-Images

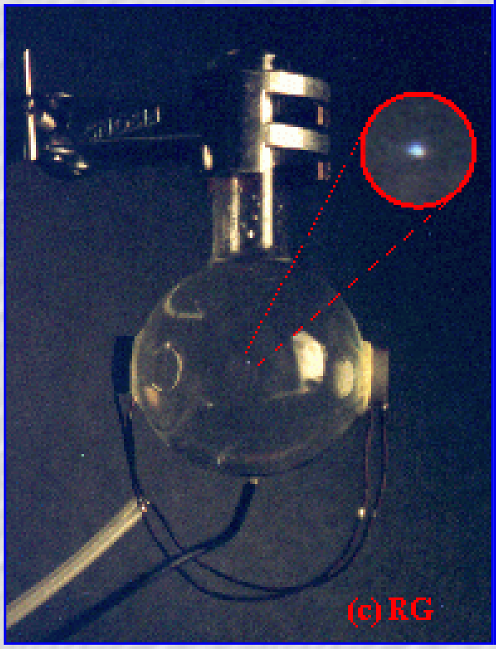
SBSL:

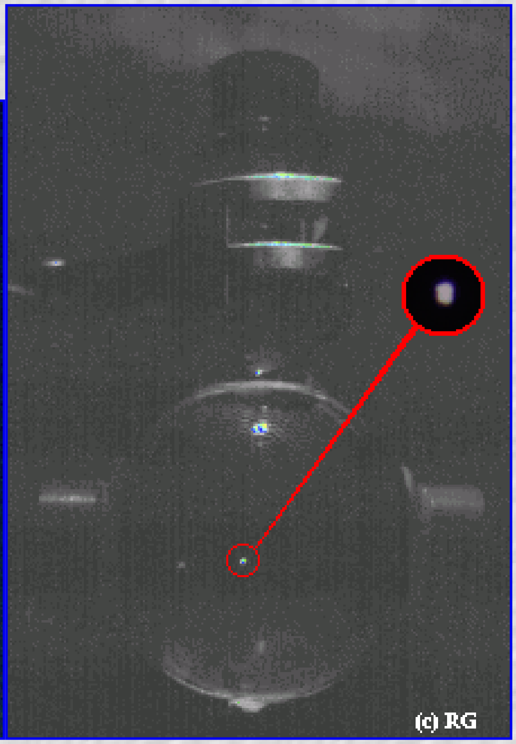
source: http://www.physik.tu-darmstadt.de/nlp/sl/



source: http://ne43.ne.uiuc.edu/ans/sonolum.html (URL does no longer exist)

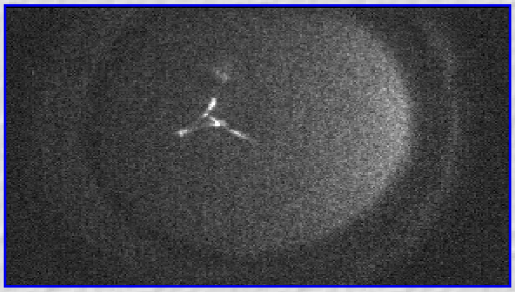
Photograph of SBSL. Study on the collapse of a single bubble in free liquid with 20 million frames per second, done with an image converter camera:





source: http://www.physik3.gwdg.de/~rgeisle/nld/sl.html

MSBL photographed with an ICCD camera and illuminated with very weak light. You have a look through the cylindrical transducer, filled with tap water, from the bottom side, which is a glass window. The transducer is driven at 20.3 kHz, approximately one bar sound filed pressure, the exposure time was 1s. You see streamers of bubbles which emit light, and therefore they form strings of lights:



source: http://www.physik3.gwdg.de/~ohl/sonoluminescence.html

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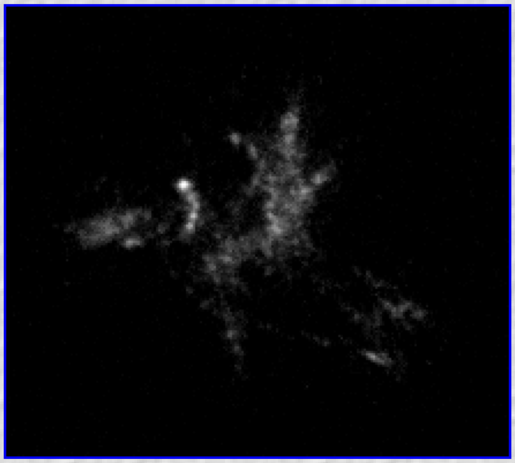
MSBL - now without illumination. The noise has been reduced by cooling also the microchannel plate (MCP) of the ICCD (-20 degree). The view is enlarged and many streamers are visible, especially the four very bright dots in the center of the picture:



source: http://www.physik3.gwdg.de/~ohl/sonoluminescence.html

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Multibubble cavitation with a large population of bubbles showing characteristic fractal distribution.

source: http://rsrch.com/saturna/sonofusion.html (Link does not longer exist)

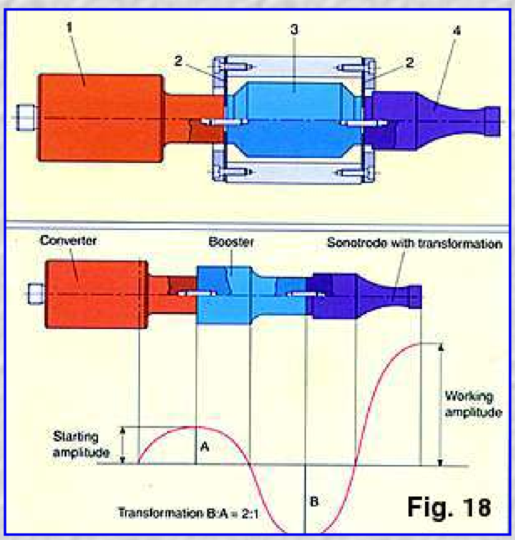
See also under cavitation for some movies !

Sonochemical Equipment and Applications

Various commercial horn systems from AEA Technology, U.K. :

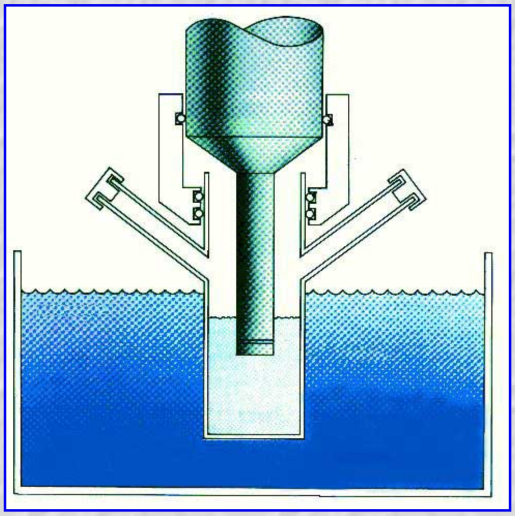
source: http://www.aeat.com/sono/ (Link does not longer exist)

Ultrasonic horn. Top: Transducer system of an ultrasonic spot-welding machine, Below: Amplitude development in the transducer system:



source: http://www.staplaultrasonics.com/book.htm

Scheme of an ultrasonic horn setup:



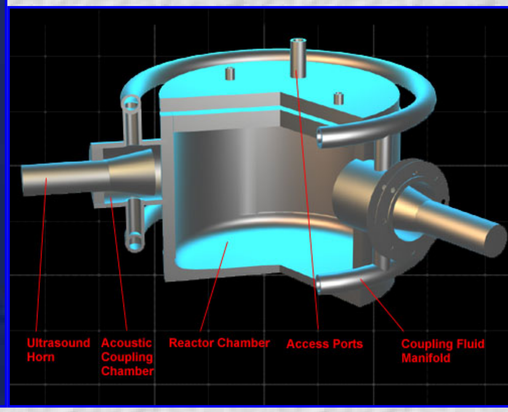
source: Kenneth Suslick

see also: *Spektrum der Wissenschaft*, Special edition "Chemistry", 1995, pp. 96-98

Sonochemical pilot plant from AEA Technology, U.K. :

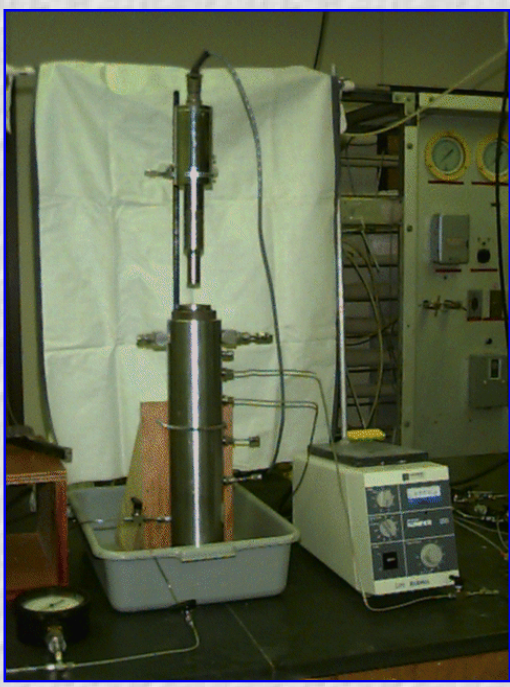
source: http://www.aeat.com/sono/

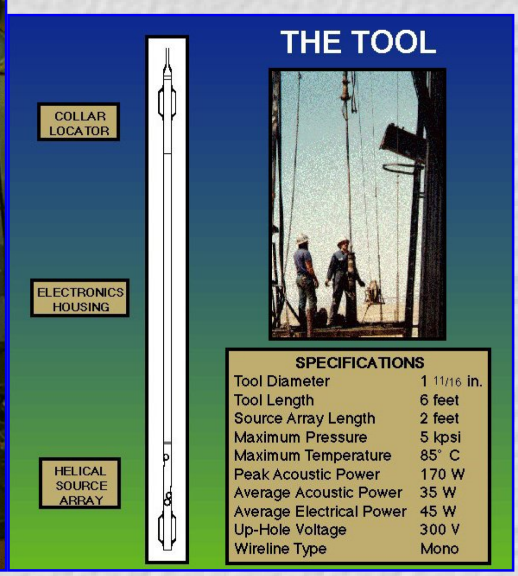
Scheme of a modular flow reactor system (1.5, 3, 6 & 12 KW modules) from AEA Technology, U.K. :



source: http://www.aeat.com/sono/

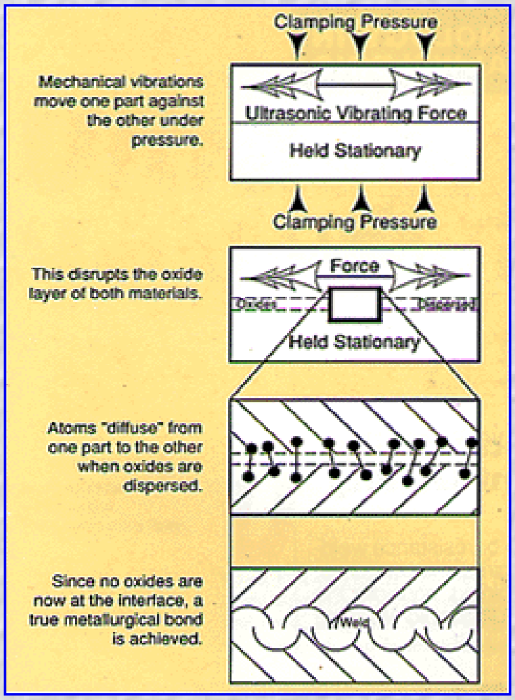
Ultrasonic reduction of wellborne deposits and formation damage in oil drilling. Images of the laboratory apparatus (left) and the prototype cleaning tool setup (right):





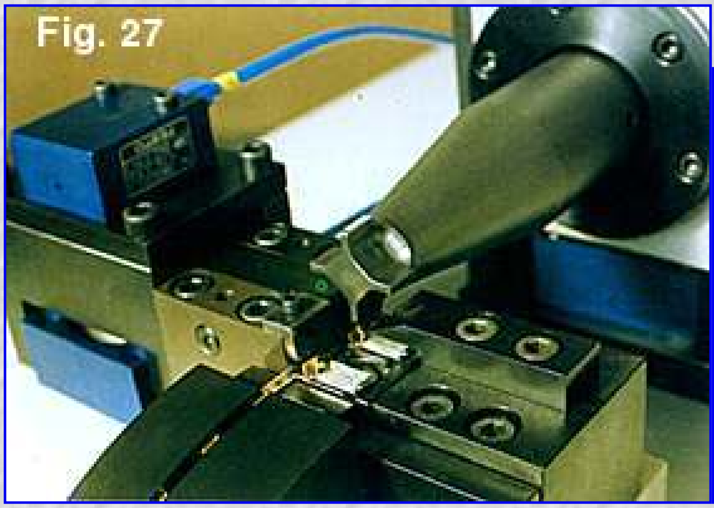
source: http://qvack.lanl.gov/Ultrasonics/ULTRASONICS.HTML (URL does no longer exist)

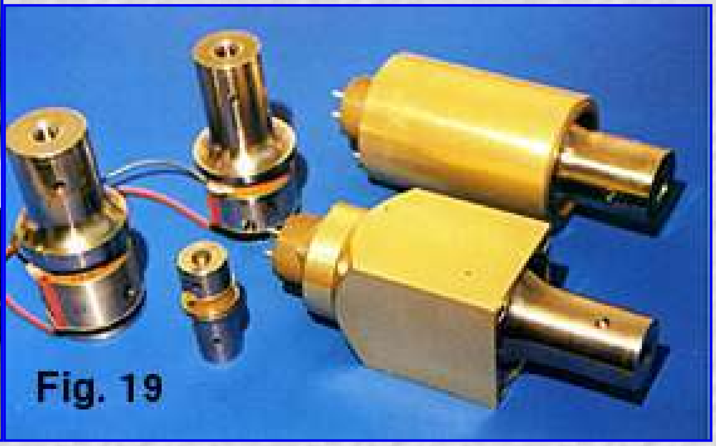
Scheme of ultrasonic metal welding:



source: http://www.staplaultrasonics.com/book.htm

Ultrasonic metal welding apparatus. Left (Fig. 27). Sonotrode and Anvil, Right (Fig. 19). Various sonotrodes:

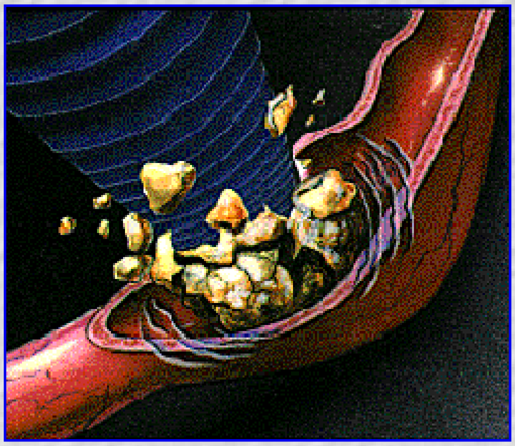




source: http://www.staplaultrasonics.com/book.htm

Medical Ultrasound

Principle of extracorporeal shock wave lithotripsy:



source: http://pluto.apl.washington.edu/harlett2/artgwww/acoustic/medical/litho.html

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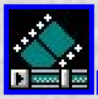
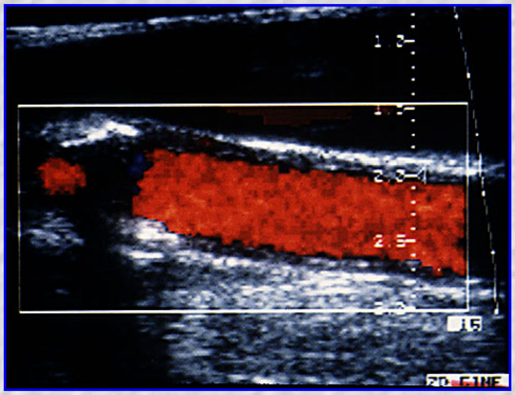
This visualization movie demonstrates the concept of focused ultrasound. The body parts model was created from CT data. The cone shows where the energy of the ultrasound is directed and which organs are intersected by the beam. The beam is focused on a tumor on the kidney. The technique used to show the cone is called texture cutting:

**Focused ultrasound on a kidney tumor**

source: http://www.crd.ge.com/esl/cgsp/projects/medical/

Ultrasound scan of carotid artery:



source: http://radiology.bidmc.harvard.edu/Modalities/Ultra/ultrasound.html (Link does not longer exist)

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BEST 1024 x 768 High Color

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Sonochemistry - Meetings

2000

May 14 - 18	7th Meeting of the European Society of Sonochemistry (ESS 7), Biarritz,(France)
May 30 - June 3	139th Meeting of the Acoustical Society of America, Atlanta, Georgia, (USA)
June 11 - 14	30th Annual Symposium of the Ultrasonics Industry Association, Ohio, (USA)
November 28 - 29	9th Symposium of the Japan Society of Sonochemistry (JSS9), Yokohama, (Japan)
December 4 - 8	140th Meeting of the Acoustical Society of America, Newport Beach, California, (USA)
December 11	Sonochemistry Information Day of the DECHEMA, Frankfurt/M. (Germany)

2001

January 22	2nd Meeting on Innovative Energy Sources in Chemical Engineering, Dortmund (Germany)
June 4 - 8	141st Meeting of the Acoustical Society of America, Chicago, Illinois (USA)
May 6 - 7	3rd Conference on Applications of Power Ultrasound in Physical and Chemical Processing, Toulouse (France)

May 10 - 12	First International Workshop on the Application of High Intensity Focused Ultrasound (HIFU) in Medicine, Chongqing (China)
July 2-5	Ultrasonics International 2001, Delft (The Netherlands)
September 2 - 7	17th International Congress on Acoustics, Rome (Italy)
October	10th Symposium of the Japan Society of Sonochemistry (JSS100), Tokyo (Japan)
October 11 - 12	31st Annual Symposium of the Ultrasonics Industry Association, Atlanta (USA)
December 3 - 7	142nd Meeting of the Acoustical Society of America, Ft. Lauderdale, Florida (USA)

2002

June 3 - 7	143rd Meeting of the Acoustical Society of America, Pittsburgh, Pennsylvania, (USA)
September 14-19	8th Meeting of the European Society of Sonochemistry (ESS 8), Villasimius (Italy)
December 2 - 6	Joint Meeting: 144nd Meeting of the Acoustical Society of America, 3rd Iberoamerican Congress of Acoustics and 9th Mexican Congress on Acoustics, Cancun, (Mexico)

2003

September 7-10	World Congress on Ultrasonics, Paris, (France)

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Sonochemistry - FAQ

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