European Cooperation in the field of Scientific and Technical Research - COST -

Secretariat

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COST 229/04

DRAFT MEMORANDUM OF UNDERSTANDING

Subject :	Draft Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action P14 "Laser-matter interactions with ultra-short pulses, high-frequency pulses and ultra-intense pulses. From attophysics to petawatt physics (ULTRA)"

Delegations will find attached the abovementioned Memorandum of Understanding.

DRAFT

MEMORANDUM OF UNDERSTANDING

FOR THE IMPLEMENTATION OF A EUROPEAN CONCERTED RESEARCH ACTION DESIGNATED AS

COST P14

“LASER-MATTER INTERACTIONS WITH ULTRA-SHORT PULSES, HIGH-FREQUENCY PULSES AND ULTRA-INTENSE PULSES. FROM ATTOPHYSICS TO PETAWATT PHYSICS

(ULTRA)“

The Signatories to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the Technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 400/01 “Rules and Procedures for Implementing COST Actions”, the contents of which the Signatories are fully aware of.

2. The main objective of the Action is to develop greater understanding of the physics of atoms, molecules, clusters, solids and plasmas interacting with high-intensity coherent light.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at Euro 20 million in 2003 prices.

4. The Memorandum of Understanding will take effect on being signed by at least five Signatories.

5. The Memorandum of Understanding will remain in force for a period of four years, calculated from the date of first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of Chapter 6 of the document referred to in Point 1 above.

LASER-MATTER INTERACTIONS WITH ULTRA-SHORT PULSES, HIGH-FREQUENCY PULSES AND ULTRA-INTENSE PULSES. FROM ATTOPHYSICS TO PETAWATT PHYSICS (ULTRA)
COST P14

A. BACKGROUND

The study of the interaction of matter with high-intensity laser fields is an important new and rapidly expanding branch of physics. The potential applications of this research are enormous, not only in physics, but also in chemistry, biology, medicine, material science and in the fast ignition approach to inertial confinement fusion.

Recent progress in laser technology has revolutionised the production of high-intensity coherent light. The next decade will be that of the application of new light sources delivering i) super-intense terawatt (10^{12}W) few-cycle pulses in the visible or near-infrared region, ii) high-frequency ultra-short attosecond (10^{-18}s) pulses and longer intense pulses of XUV and X-ray radiation from free-electron lasers and plasma-based lasers, and iii) ultra-intense pulses at optical frequencies from table-top terawatt (10^{12}W) and from petawatt (10^{15}W) lasers. The perspectives opened by these new light sources are tremendous.

1. In the visible or near infrared regions, terawatt laser pulses can now be generated which comprise only a few cycles of oscillation of the electromagnetic field. The availability of such ultra-short, few cycle pulses has opened a new, exciting research area in the study of matter interaction with super-intense laser fields. In particular, these pulses can be used for the production of attosecond VUV and XUV pulses by high-order harmonic generation in gases. Very recently, the possibility to control the „carrier-envelope“ offset of few-cycle pulses (namely the phase difference between the maximum of the pulse envelope and the maximum of the most central oscillation of the laser electric field) has been demonstrated. Recent studies indicate that this carrier-envelope offset plays an important role in multiphoton ionisation and in the generation of high-order harmonics. The use of intense few-cycle pulses also opens the possibility to study ultra-fast processes in laser-plasma

interactions, such as collective electron processes in very dense plasmas, plasma surfaces and small clusters. The Coulomb explosion of bio-molecules occurs on the time scale of a few femtoseconds (10^{-15}s) and sufficiently intense few-cycle pulses may become an important innovation for bio-sciences.

2. In contrast to optical electromagnetic radiation, high-frequency radiation can be used to probe and shape matter on spatial scales below the Angstrom (10^{-10}m) and on temporal scales below the femtosecond. Recent experiments show evidence for the production, through high-order harmonic generation, of single attosecond pulses (using few cycle laser pulses) or attosecond pulse trains (using longer laser pulses). These attosecond pulses have a broad spectrum, of the order of several eV, and a central frequency in the extreme ultraviolet range, typically from 10 eV to 100 eV. The availability of attosecond pulses opens a new research field: "attophysics". Such pulses will extend the domain of pump-probe experiments into the attosecond range where it will be possible to follow the electronic motion in matter just as the femtosecond pulses have allowed in the past few years to follow the nuclear motion in molecules. In addition, longer, intense, high-frequency (XUV and X-ray) pulses can now be generated from free-electron lasers (like the TESLA Test facility at DESY, Hamburg), and from plasma-based lasers. Because of their high intensity, these novel XUV and X-ray pulses will allow the study of entirely new classes of non-linear laser-matter interactions, such as atomic inner-shell multiphoton ionisation and multiphoton multiple hole creation followed by Auger decay. The extension of high-power laser beams towards higher-frequencies in the XUV and X-ray regimes is also very important for the study of dense plasma physics, because these beams not only allow to heat matter up to keV temperatures and gigabar pressures, but also to diagnose the microscopic plasma structure by means of the scattered radiation.

3. The development of laser systems producing ultra-intense petawatt pulses at optical frequencies (at Rutherford-Appleton Laboratory, LULI and GSI-Darmstadt) has opened new areas of laser-plasma physics with gases, clusters and solids as target material. Exploring new physics with these petawatt systems, but also with 10-100 terawatt systems of table-top dimensions (available for example at Lund, Max-Born-Institute in Berlin and Max-Planck-Institute for Quantum Optics in Garching) has just started. Generation of well-collimated beams of relativistic electrons and ions with ultra-high currents (10-100 kA) and huge magnetic fields (up to gigagauss) is a central topic. This offers the possibility to produce

ultra-short, ultra-bright secondary beams of X-rays, neutrons and positrons and should lead to a variety of applications, in particular in materials research (diagnostics) and in medicine (radiation therapy, isotope production). The potential for new types of accelerators for GeV electrons and ions as well as new types of particle sources for existing accelerators is also under discussion. In plasma-based accelerators, acceleration fields of the order of 10^{12}V/cm can be obtained compared to 10^{6}V/cm in conventional accelerators, suggesting that the size of accelerators could be considerably reduced. Another important application is to laboratory astrophysics, where the physics of matter under extreme conditions (very high densities and/or temperatures) can be explored using ultra-intense laser pulses. The focus in this case is on the study of ultra-high magnetic fields and current transport, together with related phenomena such as filamentation and radiative shocks. These studies have important applications for astrophysics since states of matter present in the interior of stars and large planets can now be created in the laboratory, and their properties investigated. Another crucial application concerns the fast ignition approach to inertial confinement fusion (ICF). This method of achieving ICF offers the advantage of efficient coupling between the laser radiation and electrons. The ICF laboratories at Livermore, Rochester and Bordeaux are all planning to add a petawatt laser for this purpose. A central topic, to be investigated within this Action, is to obtain a better understanding of the transport processes of fast electrons in dense matter, in the relativistic regime, thereby allowing improved ignition schemes to be developed. The success of the fast ignition approach to ICF could lead to a solution of the crucial problem of energy supply.

Complementarity with ongoing research in Europe

This Action will draw from the networks and experience built up within the ESF-PESC "FEMTO" programme, chaired by Prof. C. J. Joachain, which was launched on January 1, 1999 and ends on December 31, 2003. In the same way, complementarity is envisaged with the “ATTO“ network co-ordinated by Professors A. L’Huillier and C.G. Wahlström (Lund Laser Centre) within the Fifth EC Framework Programme. There will also be a positive synergy with the present „LASERNET“, the EU Network of Large Scale Laser Installations, co-ordinated by Prof. W. Sandner.

B. OBJECTIVES AND BENEFITS

The main objective of the Action is to develop greater understanding of the physics of atoms, molecules, clusters, solids and plasmas interacting with high-intensity coherent light.

An additional objective is to maintain the leadership of Europe in this area of science by building upon the links between the participating research teams and creating larger scale collaborations. The Action, being deliberately broad in scope, aims to facilitate the co-ordination of European research on high-intensity laser-matter interactions, and in particular to develop a fruitful collaboration between the European atomic physics and plasma physics communities. It is also an important goal of this Action to broaden the training of young European scientists within the participating research groups. Via the involvement of researchers from East European countries, this Action also aims to facilitate the development of research centres in these countries. The Action can be described by the following keywords:

Ultra-fast phenomena, few-cycle pulses, attosecond pulses, high-frequency lasers, super-intense lasers, high-intensity laser-matter interactions, multiphoton processes, harmonic generation, particle acceleration in plasmas, laboratory astrophysics, inertial confinement fusion.

Benefits of the Action

The Action will:

- Increase the understanding of the physics of matter interacting with super-intense, ultra-short few cycle infrared and visible laser pulses, with applications to i) the generation of attosecond pulses in the VUV and XUV domains, ii) multiphoton processes in atoms, molecules and clusters, iii) collective electron processes in very dense plasmas, plasma surfaces and small clusters.

- Increase the understanding of the physics of matter interacting with high-frequency radiation including attosecond pulses and pulses from free-electron and X-ray lasers, with applications to i) electron dynamics and inner-shell excitations in atomic systems, ii) time-resolved Auger spectroscopy, iii) strong field multiphoton processes in atoms, molecules and clusters, iv) dense plasma physics.

- Increase the understanding of the physics of matter interacting with ultra-intense optical pulses, with applications to i) new types of accelerators for GeV electrons and ions, as well as new types of particle sources for existing accelerators, ii) laboratory astrophysics, iii) nuclear reactions induced in target materials by ultra-bright secondary beams of gamma rays and neutrons produced in laser-plasma interactions, iv) transport processes of fast electrons in dense matter, to obtain improved schemes for the fast ignition approach to inertial confinement fusion.

- Provide a forum for the development of joint research, facilitate co-ordination, enhance communication between participating research groups, and enable participants to share results.

- Broaden the training and enhance the mobility of young European scientists.

C. SCIENTIFIC PROGRAMME

The Scientific Programme is based on two mutually interlocking Working Groups (WGs). WG 1 will investigate the physics of atoms, molecules and clusters interacting with high-intensity coherent light, i.e. the physics of high-intensity laser-matter interactions at the microscopic level. WG 2 will investigate the problem at the macroscopic level, i.e. it will study the interaction of ultra-short pulses, high-frequency pulses and ultra-intense pulses with solids and plasmas. For both WGs, the work will be carried out in two phases:

1) Development of sources, instrumentation and theory to carry out and interpret experiments with ultra-high temporal resolution, high-frequency pulses and ultra-intense pulses.

2) Investigation of laser-matter interaction phenomena with ultra-short pulses, high-frequency pulses and ultra-intense pulses.

Working Group 1: High-intensity laser-matter interactions at the microscopic level

This group will bring together experimental and theoretical physicists to work on the following two projects:

Project 1: Interaction of atoms, molecules and clusters with super-intense, ultra-short few cycle infrared and visible laser pulses and generation of attosecond pulses.

Phase 1

- Increase of ultra-short, few-cycle pulse power using post-compression techniques and optical parametric chirped pulse amplification.
- Phase control of high power laser pulses.
- Generation of attosecond pulses using ultra-short super-intense laser pulses.
- Improvement of electron and ion detection using coincidence and imaging techniques.
- Development of theoretical methods to study the interaction of atoms, molecules and clusters with super-intense few-cycle laser pulses.

Phase 2

- Investigation of strong field processes with phase-controlled few-cycle pulses.
- Detailed calculations, including electron correlations and pulse propagation effects.

Project 2: Interaction of atoms, molecules and clusters with high-frequency radiation including attosecond pulses and pulses from free-electron lasers and X-ray lasers

Phase 1

- Characterisation in the temporal and spatial domain of XUV attosecond pulses.
- Investigation of the phase locking between consecutive harmonics, prerequisite to the formation of attosecond pulse trains.

- Generation of single attosecond pulses using polarisation gating. Comparison with the approach using intense few-cycle pulses, developed in Project 1.
- Development of pump-probe instrumentation for attosecond experiments and for combined laser-X-ray experiments with ultra-high temporal resolution at large-scale X-ray facilities.
- Development of laser-based table-top VUV and X-ray sources of sufficient intensity for the study of nonlinear processes.
- Development of the requisite theoretical methods for the study of nonlinear processes in the interaction of high-frequency radiation with simple atomic systems.

Phase 2

- Time-resolved attosecond spectroscopy of atoms and molecules.
- Experimental study of non-linear processes in the interaction of high-frequency, high-intensity radiation with atoms, molecules and clusters.
- Detailed calculations of non-linear high-frequency processes.

Working Group 2: High-intensity laser-matter interactions at the macroscopic level

This WG will bring together experimental and theoretical physicists to work on the following two projects:

Project 3: Laser-plasma physics with ultra-short pulses, high-frequency pulses and ultra-intense pulses

Phase 1

- Development of few-cycle terawatt laser pulses (e.g. at LOA Palaiseau and TU Wien) for the study of laser-plasma interactions.
- Extension of high-power laser beams towards higher frequencies in the XUV and X-ray regime. A first option is to use plasma-based X-ray lasers. In particular, the PALS Research Centre at Prague now operates a double-pass zinc laser delivering 100 fs, 4 mJ, 40 TW pulses of 58,5 eV photons.

- Use of existing lasers in the 10-100 TW regime, reaching intensities up to several 10^{19} W/cm^2 (e.g. at LLC Lund, MBI Berlin, MPQ Garching and the University of Jena) for experiments on basic super-intense laser-plasma physics.
- Development of particle-in-cell simulations to understand the non-linear structures of relativistic laser-plasma interactions, as well as analytic modelling.

Phase 2

- Use of few-cycle terawatt laser pulses to study ultra-fast processes such as super-radiant amplification of ultra-short pulses and collective electron processes in dense plasmas.
- Use of the TESLA Test Facility to study new properties of dense plasmas, in particular metal critical points.
- Use of ultra-intense petawatt lasers with single-shot pulses of some 100 fs and intensities up to 10^{22} W/cm^2 (at Rutherford Appleton Laboratory, LULI and GSI-Darmstadt) to perform experiments on relativistic laser-plasma interactions, ultra-high current transport (up to 10^{14} A/cm^2) and huge magnetic fields (gigagauss).
- Simulation of the experiments using the developed codes.

Project 4: Applications of laser-plasma studies to particle acceleration, laboratory astrophysics, laser-induced nuclear reactions and the fast ignition approach to inertial confinement fusion

Phase 1

- Development of laser sources and instrumentation to study applications of laser-matter interactions to particle acceleration, laboratory astrophysics, laser-induced nuclear reactions and the fast ignition approach to inertial confinement fusion.
- Development and integration of the computer codes for simulations, including the detailed modeling of the relevant physical processes (fast electron transport, ion acceleration).

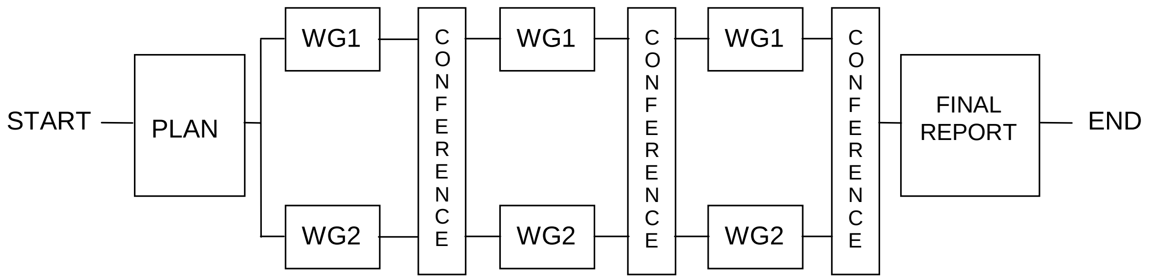
Phase 2

- Use of few-cycle terawatt laser pulses to study laser wakefield acceleration, in particular the production of monochromatic electron pulses in single wakefield buckets.

- Use of ultra-intense (petawatt) lasers to investigate the generation of collimated electron and ion beams up to GeV energies, to perform laboratory astrophysics experiments, to obtain compact ultra-bright secondary beams of gamma rays, neutrons and positrons in laser-induced nuclear reactions, and to improve the fast ignition approach to nuclear fusion.
- Production runs of computer codes for the simulation of the experiments.

D. ORGANISATION

The tasks and corresponding schedule are described below.



YEAR 1	YEAR 2	YEAR 3	YEAR 4

A Management Committee (MC) will oversee all planning, implementation and co-ordination during the Action in line with Rules and Procedures for implementing COST Actions.

Each of the two WGs defined in Section C will hold one or two workshops every year, where new methods and results will be presented, and collaborations will be stimulated.

An annual conference will be organised involving all the scientists in the Action. This conference will help the participants to keep up with all the research, ensure that cross-fertilisation occurs between the various research areas, assess key advances and foster important new directions. This conference will coincide with the annual meeting of the MC.

Short-Term Scientific Missions (STSMs) will allow researchers to work with other teams participating to the Action. This will allow them to exchange ideas, to develop fruitful collaborations and to foster joint publications.

A web site will be established that provides information for participants and also offers other services that participants may request. This site will give organisation and contact details that will enable new participants to join the Action.

E. TIMETABLE

The total duration of the Action will be four years. The first period of six months will be devoted to building the two WGs in line with the topics outlined in Section C. Discussion within the Management Committee will ensure that the work is well-focussed, that fruitful collaborations between the participants are either initiated or developed, and that a positive synergy is created between the two WGs. Each WG will hold one or two workshops per year, and a conference will be organised every year for all the participants of the Action. The annual meeting of the MC will coincide with the conference. The last six months will be devoted to the preparation of a synthesis of the results achieved, together with the final report.

F. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: Austria, Belgium, Czech Republic, Finland, France, Germany, Greece, Hungary, Italy, Lithuania, The Netherlands, Poland, Portugal, Romania, Spain, Sweden, Switzerland, United Kingdom.

On the basis of national estimates provided by the representatives of these countries, the economic dimension of the activities to be carried out under the Action has been estimated, in 2003 prices, at roughly EURO 20 million.

G. DISSEMINATION PLAN

The Action will encourage and promote co-authored papers in international journals and conferences. The support of COST will be acknowledged where appropriate.

A website will be developed that includes all relevant information and progress relating to the Action.

The aim of the workshops held by each WG will be to present and discuss in depth new methods and results, and to stimulate collaborations between the research teams.

The aim of the annual conference will be to present and discuss new achievements, give an overview to the participants, ensure cross-fertilisation between the various research fields, determine new important directions, and eventually invite new participants to the Action.