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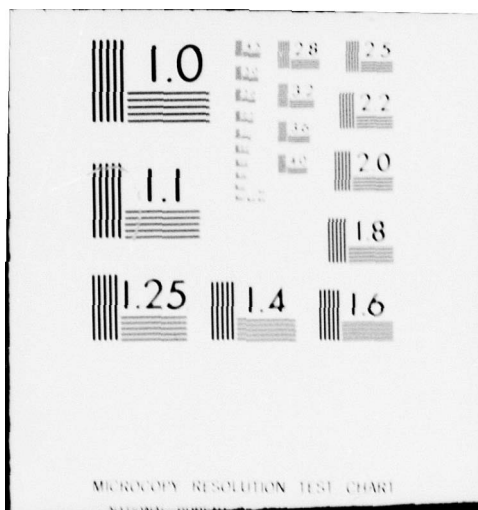
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(18) (19) AFOSR-TR-78-1502

(11) NOVEMBER 1978

(12) 25p.

(12) LEVEL II

(9) Final Scientific Report.
Oct 73 - Sep 78,
on

(6) BASIC INSTABILITY MECHANISMS
IN CHEMICALLY REACTING SUBSONIC AND SUPERSONIC FLOWS.

by

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(15) Grant No. AFOSR-74-2619
Project No. [REDACTED] 2308/A2

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Research sponsored by the Air Force Office of Scientific Research (AFSC), United States Air Force. Research monitored under the technical supervision of Dr. B. T. Wolfson, AFOSR.

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BASIC INSTABILITY MECHANISMS
IN CHEMICALLY REACTING SUBSONIC AND SUPERSONIC FLOWS

ABSTRACT

This report summarizes the main results and conclusions obtained in a research program on basic instability mechanisms in chemically reacting flows.

Both theoretical and experimental work was conducted to determine the linear and the non-linear coupling between chemical kinetics and gas dynamics, which lead to wave interactions necessary for sustaining the instabilities. Acoustic, chemical and mixed modes of instability were identified. Non-linear wave-kinetic coupling was found to be important at high activation energies for weak shocks. Threshold values of shock strength and pulse width are required to initiate detonations or explosions.

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This report summarizes the main results and conclusions obtained in a research program on basic instability mechanisms in chemically reacting subsonic and supersonic flows, conducted at the Massachusetts Institute of Technology with the support of the U.S. Air Force Office of Scientific Research under Grant AFOSR-74-2619. More detailed information may be found in the various publications listed in the Bibliography, with their abstracts attached to the end of this report.

The main objective of this program is to study basic mechanisms which play important roles in triggering and sustaining instabilities in chemically reacting flows; such as those related to combustion instabilities, combustion noise, detonation structure, stability and initiation, turbulence spectra in reacting flows, initiation and suppression of explosions, etc. One such mechanism is due to the coupling between chemical kinetics and gas dynamics, which lead to wave interactions necessary for sustaining the instabilities.

During the initial phase of the development of instabilities, the amplitudes of the waves involved are usually small and the wave-kinetic interactions can be treated in a linear acoustic analysis (despite nonlinear chemical kinetics through temperature and concentration dependence). Considerable insight on such acoustic-kinetic interactions has been obtained in several theoretical studies (1,4,6,7). Furthermore, predictions in the quasi-steady regime where the ratio of the characteristic chemical time to the acoustic period is large, are found to agree well with the experimental results on both travelling tone bursts and standing

waves in H_2-Cl_2 -Ar systems (8,9,10 and 11).

More recent effort has been devoted to the study of non-linear wave-kinetic interactions involving weak shocks. Experiments show that the shock strengths are amplified due to chemical reaction. Furthermore, the amplification rates measured at low frequencies are found to be higher than those predicted by the quasi-steady theory, thus suggesting frequency dependence in chemical effects. At shock Mach numbers above 1.15, non-linear wave-kinetic interactions begin to play a role in sustaining and amplifying the shock strength, despite high dissipative losses at the shock front. Concurrent theoretical work further shows that threshold values for both shock strength and pulse width are required in order to initiate detonation or explosion.

(I) Acoustic-Kinetic Interactions

(A) Theoretical Investigation

One of the important relevant questions is concerned with possible chemical effects on generation and amplification of acoustic waves and their propagation. Unlike sound propagation in gaseous media at chemical equilibrium, when only attenuation is observed, acoustic waves can be either amplified or attenuated, depending upon specific conditions, through coupling between non-equilibrium chemical kinetics and sound propagation (1,4,6,7).

Chemical effects are in general of two kinds; viz., those due to changes in the mean conditions, resulting from transient chemical reaction,

and those due to fluctuations in the reaction rates, resulting from acoustic waves. These acoustic-kinetic interactions depend on the order and enthalpy of reaction, activation energy, and the ratio of the characteristic chemical to acoustic time.

Examination of the acoustic-chemical system after the completion of the reaction shows the presence of the chemical, acoustic and mixed modes of instability. The chemical mode appears as a stationary yet spatially non-uniform entropy distribution, even though the medium initially (before reaction) is uniform throughout. The acoustic mode appears as a composite of right- and left-travelling pressure or velocity waves, even though the initial acoustic wave is only right-travelling. The left-travelling wave is generated due to partial reflection or scattering as the right-travelling wave propagates in a spatially inhomogeneous medium during the chemical reaction and is sustained even after the reaction is completed. The mixed modes of density and temperature fluctuations apparently retain to some degree the characteristics of both the acoustic and the chemical modes and may, under certain conditions, be dominated by either one of the modes of behavior. This is determined largely by the parameter Ω , the ratio of chemical to acoustic time scales.

During reaction, it is found that the observed complicated behavior can also be interpreted fruitfully in terms of the mode concept developed for the post-reaction behavior. It is observed that the temporal development of the physical fluctuating variables is dependent upon spatial

position (the effect being stronger as Ω is reduced). Further, it is found that at specific values of Ω , the following effects are maximized:

- (i) acoustic amplification
- (ii) wave reflection
- (iii) reaction evolution enhancement

The energy contained in the fluctuations is found to be composed of an acoustic and a chemical part. The latter dominates during reaction. However, after reaction, the chemical part exactly balances any change in the acoustic part which occurs during reaction, thus resulting in no net change in the fluctuation energy. The chemical part seems to represent the loss (or gain) of mean thermal energy which was diverted by chemi-acoustic interactions into the increased (or decreased) acoustic energy of the system.

For the quasi-steady limit (high acoustic frequency or slow reaction), an approximate analytical solution employing a Sylvester expansion has been obtained in terms of four normal fluctuation modes which permit critical examination of the physics of acoustic-kinetic coupling. Essentially, the chemical effects are manifested in the amplification (or attenuation) of the acoustic waves, without resulting in much scattering and the generation of entropy modes.

(B) Experimental Investigation

The propagation of acoustic waves in a homogeneous mixture of hydrogen and chlorine (diluted with argon) was examined in a 5.5-m long, 8-cm diameter Pyrex tube, surrounded by dc fluorescent black-light lamps

(8,9,10,11). The photochemical reaction between hydrogen and chlorine was initiated by ultraviolet radiation from the fluorescent lamps incident onto the premixed, homogeneous reactive mixture. The overall reaction rate was measured by monitoring the quantity of uv light absorbed by molecular chlorine with a photomultiplier, equipped with a narrow-band filter, and the mean temperature of the gas by means of tungsten-wire resistance thermometers. The average chlorine consumption rate and the corresponding mean temperature history were thus available for each experiment.

Two different wave configurations were employed in this investigation. In one configuration, sound waves were generated at one end of the reaction tube by means of a piston, actuated by a mechanical shaker. A pulse generator-function generator-power amplifier combination was used to generate a 2-cycle burst of a given frequency which propagates down the tube. Sound pressure was monitored at various stations along the tube by means of several miniature condenser microphones. The incident burst reflected back and forth at both ends of the tube and as a result, one was able to examine a specific 2-cycle burst during a time interval as long as 1/2 sec, before its amplitude reached the noise level due to dissipation. This mode of operation was used for high acoustic frequencies (300 to 900Hz).

In the other configuration, the piston shaker was used to establish first a standing wave in the reaction tube at one of its resonant frequencies. Once the wave attained its maximum amplitude, the piston-

shaker was turned off and the reaction initiated. This mode of operation was used at lower acoustic frequencies (32 and 64 Hz).

In both modes, the behavior of the resulting wave during the photochemical reaction was monitored by microphones and compared with that in a non-reacting mixture. The sound amplitudes during reaction are invariably higher than those in a non-reacting medium. Furthermore, the measured amplification rates (which have been obtained at large values of Ω) agree well with the predicted rates on the basis of the quasi-steady theory. The measured rates are also found to be independent of the initial sound pressure level of the standing waves, thus confirming the linear approximation employed in the theoretical analysis.

(II) Shock-Kinetic Interactions

(A) Experimental Investigation

In order to study the non-linear wave-kinetic interactions, the amplitudes and structure of weak shocks propagating in hydrogen-chlorine-argon mixtures are examined in two other Pyrex tubes (10,11). In one case, planar weak shocks of controlled strengths and widths are generated when a high-voltage capacitor discharges through a solenoid in contact with a thin metallic diaphragm at one end of the reaction tube. The shock examined consists of a typical N-wave with a steep leading front followed by weaker trailing waves of lower amplitudes and frequencies.

Experiments show that the shock strengths are amplified due to chemical reaction. However, the trailing waves show much higher amplification rates. When compared with the quasi-steady predictions, the

leading shocks show good agreement, while the trailing waves display amplification rates that are much higher than the predicted values, because their corresponding values of Ω are lower and fall in the non-quasi-steady regime. Such behavior agrees with the theory, which predicts stronger acoustic-kinetic interactions as the characteristic acoustic time approaches the characteristic chemical time.

Except for the frequency effect on the amplification rates described above, no significant non-linear effect has been observed when the Mach number of the leading shocks is approximately 1.05. Currently, work is in progress^{*} with leading shock Mach numbers above 1.15. Despite the high dissipative loss at the shock front, the waves are sustained by chemical reaction. For high reaction rates, the waves can develop from a decaying $(1/2)N$ wave into a rapidly expanding shock pulse. It is believed that non-linear wave-kinetic interactions begin to play a role in these experiments.

(B) Theoretical Investigation

Concurrent with the experimental investigation, theoretical work is in progress to examine the non-linear wave-kinetic interactions. Preliminary work shows the significant role played by the activation energy in determining whether a shock of specific strength and pulse

^{*}This research is being continued with the support of the U.S. Air Force Office of Scientific Research under Grant AFOSR-78-3662.

width would amplify rapidly to initiate explosion or detonation. Furthermore, minimum pulse width is required for shock of a given initial strength to develop into a stronger shock. These results seem to indicate that threshold values for both shock strength and pulse duration exist for direct initiation of explosions.

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CHEMICAL EFFECTS ON SOUND PROPAGATION

by

Tau-Yi Toong

COMBUSTION AND FLAME 18, 207-216 (1972)

ABSTRACT

A theoretical study of coupling between chemical kinetics and sound propagation is presented. Examination of equations governing propagation of a travelling acoustic wave in a chemically reacting, stagnant, gaseous medium shows that chemical effects are, in general, of two kinds; viz., those due to changes in mean conditions resulting from chemical reaction and those due to fluctuations in reaction rate resulting from acoustic waves. These coupled effects are found to depend on activation energy, enthalpy of reaction, and ratio of chemical to acoustic time, and have, in particular, different qualitative features for exothermic and endothermic reactions. Several cases have been investigated. When chemical time is long as compared with acoustic time, the main effects are due to fluctuations in the reaction rate. If reaction rates increase with rising temperatures, the acoustic waves are amplified for exothermic reactions and attenuated for endothermic reactions. The sound propagation speed is only slightly reduced from its isentropic frozen value within the region of validity of this quasisteady analysis.

When the reaction rate is constant, the chemical effects are due to changes in the mean conditions. Contrary to what is predicted for the quasisteady case, the acoustic waves are here attenuated for exothermic reactions and amplified for endothermic reactions. Furthermore, effects on propagation speeds become pronounced.

When both kinds of chemical effects are considered, the results depend strongly on activation energy. For the case of small activation energy, where the reaction rate is weakly dependent on temperature, the qualitative effects are similar to those observed for constant reaction rate. For large activation energy, however, effects due to fluctuations in reaction rate become pronounced, leading to amplification for exothermic reactions and attenuation for endothermic reactions.

In all cases, chemical effects become more significant at higher reaction rates.

A THEORETICAL STUDY ON GENERATION OF VORTICITY
DUE TO CHEMICAL REACTION

by

Patrick A. Arbeau

Submitted to the Department of Mechanical Engineering on June 20, 1972
in partial fulfillment of the requirements for the degree of Master of
Science.

ABSTRACT

The possible generation of vorticity by combustion is studied, for different models of turbulent flames. Examination of the viscous, compressible vorticity equation shows that the effect of combustion might be of two kinds; viz., a "density effect," due to the change of size of the eddies by change of density, and a "pressure-density effect," due to simultaneous occurrence of non-parallel gradients of pressure and gradients of density.

For the "wrinkling laminar flame" model, an expression has been found for the change in vorticity for a particle crossing a flame front, assumed the combustion zone to be very thin, and the flame locally laminar. It is found that the change in vorticity depends strongly on the mean square pressure gradient at the flame front. Two mechanisms are considered, whether the intensity of the turbulence in the flow upstream is weak or strong, and the influence of the relevant parameters is discussed, in each case.

For the case of "volume combustion," an analysis similar to Kármán and Howarth's analysis for isotropic homogeneous turbulence has been performed, leading to a mean-square vorticity equation valid when combustion occurs. New correlations in this equation indicate the averaged effects of chemical reaction on vorticity. Examination of the term corresponding to "pressure-density effect" shows that it results from the second-order interaction between the sound and entropy modes. Experimental measurements of the new correlations could determine the magnitude of combustion generated turbulence.

Interaction of sound waves with occurrence of chemical reaction as a possible mechanism of generation of vorticity is then examined. An homogeneous stagnant, chemically reacting medium, and two travelling waves are considered. Numerical resolution of the governing equations shows the influence of some of the relevant parameters, and estimates the order of magnitude of the generated vorticity.

Thesis Supervisor: Tau-Yi Toong
Title: Professor of Mechanical Engineering

INSTABILITIES IN REACTING FLOWS

by

Tau-Yi Toong

Acta Astronautica, 1, 317-344, 1974

ABSTRACT

This paper reviews non-steady phenomena in reacting flows arising through coupling between chemical kinetics and gas dynamics. Problems examined include piston-supported detonations, exothermic hypersonic flows about blunt and conical projectiles, transient development of instabilities in blunt-body flows and in propagating detonations, acoustic-kinetic interactions and vorticity generation. The interrelationships among the various problems are examined in terms of the governing instability mechanism. Unsolved but critical problem areas are also identified.

In the theoretical studies of piston-supported shock waves in an exothermally reacting mixture, periodic instabilities have been found to develop to well-defined amplitudes and periods. These results agree well with those predicted on the basis of a wave-interaction model, which clearly demonstrates the physics involved in the coupling between gas dynamics and chemical kinetics. They also agree well with the experimental results observed in exothermic hypersonic flows about blunt projectiles in a ballistic range.

Recent experiments on exothermic hypersonic flows about conical projectiles show the existence of two instability regimes in addition to steady over-driven and Chapman-Jouguet detonations. One of the two instability regimes shows flow features which resemble remarkably well with those observed around blunt projectiles, while the other regime clearly shows features peculiar to conical flows.

In order to understand the coupling mechanisms in greater details, experiments have been conducted in a ballistic range to study the initiation and the decay of the two instability regimes around blunt projectiles across compositional interface. Similar transient studies have been performed with propagating detonation waves that encounter either compositional or tube-area changes. Much deeper understanding has been achieved.

Unlike sound propagation in gaseous media at chemical equilibrium, when only attenuation is observed, traveling acoustic waves can be amplified under some conditions through coupling between non-equilibrium chemical kinetics and acoustic fluctuations. In another theoretical study, generation of vorticity fluctuations has been predicted, as the consequence of sound-entropy interactions in the presence of chemical reactions. These studies have led to a better understanding of the role of chemical reactions in basic instability mechanisms.

BASIC INSTABILITY MECHANISMS
IN CHEMICALLY REACTING SUBSONIC AND SUPERSONIC FLOWS

by

Tau-Yi Toong

U.S. Air Force Office of Scientific Research, Final Scientific Report,
No. AFOSR-TR-74-0065, November 1973.

ABSTRACT

This report summarizes the main results and conclusions obtained during the contract period in two studies, both aimed at understanding the instability mechanisms in reacting flows.

In one study, both theoretical and experimental work is conducted to determine the fluid-dynamic and chemical-kinetic mechanisms by which instabilities are triggered in flows around spherical, cylindrical and conical projectiles fired at supersonic speeds into reactive gaseous media as well as their effects on heat-release rates and approach to chemical equilibrium in the shock layer and inviscid wake. Although the main flow features are different, depending on whether the projectiles are blunt-nosed or conical, the instabilities observed can be explained on the basis of one single mechanism, involving wave interactions in reacting flows.

Experiments have also been conducted with spherical projectiles to examine the initiation and the decay of the instabilities when they are moving from an exothermally reacting mixture of one composition to another. Supported by a concurrent theoretical study, these transient experiments yielded some useful information.

In another study, the detailed mechanisms in which the instabilities are triggered in reacting media have been examined. Possible chemical effects on sound propagation and vorticity generation have been identified.

ACOUSTIC-KINETIC INTERACTIONS
IN AN IRREVERSIBLY REACTING MEDIUM

by

Tau-Yi Toong, Patrick Arbeau, Charles A. Garris,
and Jean-Pierre Patureau

Fifteenth Symposium (International) on Combustion, The Combustion
Institute, Pittsburgh, Pa., 87-100, 1975.

ABSTRACT

Acoustic-kinetic coupling in a gaseous medium undergoing an exothermic irreversible reaction with Arrhenius kinetics is studied in both the quasi-steady and non-quasi-steady regimes.

For the quasi-steady limit (high acoustic frequency or slow reaction) an approximate analytical solution employing a Sylvester expansion is obtained in terms of four normal modes which permits critical examination of the acoustic-kinetic coupling. The amplification or attenuation behaviors and the propagation speeds are characterized by analytical expressions for density, entropy, and concentration fluctuations. It is shown that non-acoustic oscillations are possible; the existence of a sound wave reflection effect is indicated; and acoustic wave instigation of chemical instability is predicted.

The instantaneous amplitudes, phases, and speeds of propagation of density, velocity, and pressure fluctuations are studied numerically by means of a transformation for both the quasi-steady and non-quasi-steady cases.

In the quasi-steady case, all fluctuations have nearly equal phase and propagate at nearly the frozen isentropic speed of sound. However, their amplification characteristics are, in general, different due to the temporal variation in acoustic frequency and acoustic-kinetic interaction.

In the non-quasi-steady case, the instantaneous amplitudes, phases, and speeds of propagation oscillate about base lines very close to their respective quasi-steady limit curves; an indication that frequency-

dependent selective amplification and dispersion effects in wave packets are small. Furthermore, the instantaneous phases and speeds of propagation are different for the different fluctuating variables. The instantaneous amplification or attenuation of density fluctuations is shown to be dependent upon the velocity-density fluctuation phase difference.

From an acoustic-energy study, the chemical reaction is accelerated by the presence of fluctuations for all exothermic reactions considered. Energy transport during reaction between mean sensible internal energy and mean kinetic energy is discussed.

CHEMI-ACOUSTIC INSTABILITY STRUCTURE
IN IRREVERSIBLY REACTING SYSTEMS

by

Charles A. Garris, Tau-Yi Toong,
and Jean-Pierre Patureau

Acta Astronautica, 2, 981-997, 1975

ABSTRACT

A basic understanding of the structure of the interactions between chemical and acoustic instabilities and the effects derived therefrom is sought for a medium undergoing one-step irreversible chemical reaction. Detailed examination of the acoustic-chemical system after the completion of the reaction shows the distinct presence of the chemical, acoustic, and mixed modes of instability. The chemical mode appears as a stationary yet spatially inhomogeneous entropy distribution, even though the medium initially (before reaction) is homogeneous throughout. The acoustic mode appears as a composite of both right- and left-travelling pressure or velocity waves, even though the initial acoustic wave is only right-travelling. The left-travelling wave is generated due to partial reflection or scattering as the right-travelling wave propagates in a spatially inhomogeneous medium during the chemical reaction and is sustained even after the reaction is completed. The mixed modes of density and temperature fluctuations apparently retain to some degree the characteristics of both the acoustic and the chemical modes and may, under certain conditions, be dominated by either one of the modes of behavior. This is determined largely by the parameter Ω , the ratio of chemical to acoustic time scales.

During reaction, it is found that the observed complicated behavior can be interpreted fruitfully in terms of the mode concept developed for the post-reaction behavior. It is observed that the temporal development of the physical fluctuating variables is dependent upon spatial position (the effect being stronger as Ω is reduced). Further, it is found that at specific values of Ω , the following effects are maximized: (a) acoustic amplification; (b) wave reflection; (c) reaction evolution enhancement.

The energy contained in the fluctuations is found to be composed of an acoustic and a chemical part. The latter dominates during reaction. However, after reaction, the chemical part exactly balances any change

in the acoustic part which occurs during reaction, thus resulting in no net change in the fluctuation energy. The chemical part seems to represent the loss (or gain) of mean thermal energy which was diverted by chemi-acoustic interactions into the increased (or decreased) acoustic energy of the system.

ACOUSTIC-KINETIC INTERACTIONS IN
NON-EQUILIBRIUM HYDROGEN-CHLORINE REACTIONS

by

Jean-Pierre Patureau

Sc.D. Thesis, Department of Mechanical Engineering, M.I.T., January, 1976

ABSTRACT

A coordinated experimental and theoretical investigation of acoustic-kinetic coupling was conducted in H_2-Cl_2-Ar mixtures undergoing irreversible photochemical reaction.

The experimental program demonstrated the existence of a relaxation phenomenon which causes sound pressure waves to amplify significantly during non-equilibrium H_2-Cl_2 reaction (total amplification of up to 60% of the initial sound amplitude were commonly observed over a typical 0.2 second sound residence time). Furthermore, analysis of the experimental results showed that the observed rate of amplification is typically three times larger than what would be expected from simple consideration of conservation of acoustic energy in a corresponding non-dissipative but temperature varying medium in the absence of acoustic-kinetic coupling. A strong correlation was determined between the instantaneous rate of amplification and the corresponding experimental value of the expression

$$\frac{1}{2\gamma T_o} \frac{dT_o}{dt} \left(m + \gamma + \frac{\beta(\gamma-1)}{T_o/T_{o,in}} \right)$$

regardless of the sound frequency and mixture composition or pressure. T_o is the mean absolute temperature of the medium (with $T_{o,in}$ its initial value before reaction), m and β are the Arrhenius kinetic parameters (order of the reaction and reduced activation energy, respectively) determined for each test by fitting the observed chlorine concentration and mean temperature histories to an Arrhenius expression and γ is the ratio of the heat capacities at constant pressure and density, respectively.

The above experimental findings were found in good qualitative and quantitative agreement with the predictions of a physical mechanism based on a theoretical model of quasi-steady acoustic-kinetic interaction.

This mechanism postulates that upon subjecting the system to a spatially inhomogeneous perturbation manifested by the sound wave, the $\text{H}_2\text{-Cl}_2$ reaction releases additional kinetic energy to the molecules in a correspondingly inhomogeneous manner, thus enhancing the local pressure gradient which drives the acoustic wave and thereby amplifying the pressure fluctuations.

EXPERIMENTAL INVESTIGATION OF ACOUSTIC-KINETIC
INTERACTIONS IN NON-EQUILIBRIUM H_2-Cl_2 REACTIONS

by

Jean-Pierre Patureau, Tau-Yi Toong
and Charles A. Garris

Sixteenth Symposium (International) on Combustion, The Combustion
Institute, Pittsburgh, Pa., 929-938, 1977.

ABSTRACT

Effects of non-equilibrium reaction on sound propagation are identified and studied by comparing the observed amplification rates with theoretical predictions.

Experiments were conducted in a Pyrex tube, filled with a homogeneous mixture of hydrogen, chlorine and argon of different initial compositions and pressures. During the photochemical reaction following ultraviolet irradiation, the amplitude of a two-cycle burst of variable frequency (generated at one end of the reaction tube) is monitored simultaneously with mixture temperature and chlorine concentration, as the sound burst propagates in the reaction tube and reflects back and forth at its two ends. After correcting for dissipation losses, one obtains the net amplification rate which would conceivably be observed in a non-dissipative reacting medium.

Significant amplification of the sound pressure fluctuations due to acoustic-kinetic interaction has been consistently observed at different acoustic frequencies and for different mixture compositions and pressures. The amplification rate is typically three times larger than what would be expected from simple consideration of conservation of the acoustic energy, thus demonstrating the significance of the additional contribution due to acoustic-kinetic coupling. (Total amplification of up to 80% of the initial sound amplitude was commonly observed over the sound residence time of 0.1 to 0.3 sec).

Within experimental accuracy, the measured amplification rates are found to agree with predictions, derived on the basis of Arrhenius kinetics, for all mixture compositions and pressures and acoustic frequencies tested. The observed effects can be interpreted by a quasi-steady theory, which is also shown to be valid for the tests reported in this paper.

ACOUSTIC- AND SHOCK-KINETIC INTERACTIONS IN
NON-EQUILIBRIUM H_2-Cl_2 REACTIONS

by

George E. Abouseif, Tau-Yi Toong
and José Converti

Seventeenth Symposium (International) on Combustion, The Combustion
Institute, Pittsburgh, Pa., in press.

ABSTRACT

Effects of non-equilibrium reaction on the propagation of acoustic and weak shock waves are examined. The observed amplification rates are compared with the theoretical predictions, and the various chemical effects are identified.

The experiments were conducted in two Pyrex tubes, filled with a homogeneous mixture of hydrogen, chlorine and argon of varying compositions and initial pressures. In the acoustic experiments, two different wave configurations are used: 2-cycle tone bursts and standing waves. During the photochemical reaction, the sound pressure levels are monitored simultaneously with the mixture temperature and chlorine concentration. The employed acoustic frequencies are such that they satisfy the quasi-steady conditions. The measured amplification rates are found to agree well with the predictions in the quasi-steady regime.

In the second part, the amplification and dispersion of weak shocks propagating in a reacting mixture are considered. Wave packets consisting of a typical N-wave, followed by weaker trailing waves of lower frequency are generated, and the individual waves are examined.

Experiments conducted in H_2-Cl_2 mixtures show that the shock strengths are amplified due to chemical effects. The trailing waves are found to amplify as high as 500% of their initial amplitudes, and the corresponding amplification rates are much higher than those predicted by the quasi-steady theory. Consideration of the non-dimensional frequency of each individual wave in the packet suggests stronger effects for the trailing waves (being at lower characteristic frequencies), a result previously predicted by theory.

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4. TITLE (and Subtitle) BASIC INSTABILITY MECHANISMS IN CHEMICALLY REACTING SUBSONIC AND SUPERSONIC FLOWS		5. TYPE OF REPORT & PERIOD COVERED FINAL Oct 73 - Sep 78
7. AUTHOR(s) TAU-YI TOONG		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS MASSACHUSETTS INSTITUTE OF TECHNOLOGY DEPARTMENT OF MECHANICAL ENGINEERING CAMBRIDGE, MASSACHUSETTS 02139		8. CONTRACT OR GRANT NUMBER(s) AFOSR 74-2619
11. CONTROLLING OFFICE NAME AND ADDRESS AIR FORCE OFFICE OF SCIENTIFIC RESEARCH/NA BLDG 410 BOLLING AIR FORCE BASE, D C 20332		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2308A2 61102F
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE Nov 78
		13. NUMBER OF PAGES 23
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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) INSTABILITY MECHANISMS LINEAR AND NON-LINEAR COUPLING WAVE-KINETIC INTERACTIONS ACOUSTIC INSTABILITY MODE ACOUSTIC-KINETIC INTERACTIONS CHEMICAL INSTABILITY MODE SHOCK-KINETIC INTERACTIONS MIXED INSTABILITY MODE INITIATION REQUIREMENTS FOR EXPLOSIONS		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report summarizes the main results and conclusions obtained in a research program on basic instability mechanisms in chemically reacting flows. Both theoretical and experimental work was conducted to determine the linear and the non-linear coupling between chemical kinetics and gas dynamics, which lead to wave interactions necessary for sustaining the instabilities. Acoustic, chemical and mixed modes of instability were identified. Non-linear wave-kinetic coupling was found to be important at high activation energies for weak shocks. Threshold values of shock strength and pulse width are required to initiate detonations or explosions.		