AD NUMBER

AD855593

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; JUN 1969. Other requests shall be referred to US Army Biological Labs., Fort Detrick, Frederick, MD.

AUTHORITY

SMUFD/Fort Detrick ltr dtd 17 Feb 1972

SUSPENDED PARTICLES IN A SOUND FIELD

Translation No. T-688-1

JUNE 1969

U. S. ARMY
BIOLOGICAL LABORATORIES
FORT DETRICK, FREDERICK, MARYLAND

SUSPENDED PARTICLES IN A SOUND FIELD

(Following is the translation of an article by O. Brandt, H. Breund and E. Hiedemann, Cologne University, which appeared in the German language periodical, Z. Physik, 1937, volume 104, pages 511-33. Translation performed by Constance L. Lust.)

In order to gain information on the mechanism of coagulation of suspended particles in a gas phase we recently studied the behavior of a single particle and a whole system in a sound field (1,2). Generally the amplitude Xp of a particle in the field in a function of the gas amplitude Xg, frequency v, radius r, density d and the viscosity n of the carrier. Koenig (3) reported a formula for swinging amplitude. Since that time interest was stimulated to determine microscopically the amplitude from these measurements (4). Koenig's formula was too involved for our purpose. By simplification we obtained a relationship which made it easily possible to oversee the behavior of an aerosol in a sound field. Lewis and Farris (5) also used this simplification in their studies. It is only important if the particles are suspended in a carrier of higher density, in other words liquids. Early work of Wagenschein also showed this in larger particles with low frequency sound waves.

For the similar problem of the amplitude of a loaded particle in an electric field, Abbot and Chen Yang showed in a thorough piece of work, the application of Stokes Law for suspended particles. Following the work of Chen Yang, Berkowitsch showed the proportionality between particle velocity and force up to velocity of 20 cm/sec. During this whole experiment the movement of the particle was found to be independent of the acceleration dispite the very rapid accelerating effect was applied to the particle with a voltage pulse in the Milliken condenser. The mobility was found to be accurate within 1% independent of whether the determination was done with an equivalent force or an accelerating movement. These results allow one to use the simple Stokes Law formula in the similar case of the movement of a particle in the gas phase. There is a limit within this law may be used if the velocity between the particle and the carrier become large . In that case one cannot limit a flow anymore. In movement without acceleration this limit is constant and is Reynold's no. Whether Reynold's no. are a valid criteria for the amplitude movements is not determined with certainty yet. For low frequency sound waves and large particles Andreede Esq. determined the Reynold's constants for the particles which coencided with those for non-accelerated movement. If we assume the validity of Reynold's criteria, then we are justful in assuming as we have already presented earlier that Stokes Formula for the realm of the frequency amplitude, particle size is valid for our investigations.

Preliminary experiments which were reports of which follow, show a crude correlation between the calculated and the experimental particle amplitudes. As far as we know, Koenig's formula for aerosol particles in a sound field has never been thoroughly investigated so that a decision can be made on it as to which precision reproduces the results. As long as the difference between the amplitude Xp of the particle and the amplitude Xg of the surrounding gas is small, the number accroding to Koenig's simplified law differ in only a minor way. When the amplitude differences become

larger (Xp/Xg=1) the differences become enormous. Even if the intensive sound fields which are of importance here are very large, Reynold's no. lead to delta in the Koenig's no. From these influences it was concluded that there are uncertainties in the experimental design. Koenig also noted this in his earlier work (3).

Oscillation of a suspended particle in a sound field

The mass of a particle in an aerosol is considered to be partically negligable compared to the mass of the particle. The resistance due to viscosity that a suspended particle has in a carrier is expressed as follows: formula 1.

As soon as Br is much less than 1, this formula is than transformed into the well known Stokes formula for stationary movement. When Xp/Xg=1 or at least 7.5 then the factors of frequency of sound and of the lower and upper sound area are substituted as a first approximation for the values in figure 2. If one takes into account the molecular discontinuity of the gas then the formula for the viscosity resistance is formula 1. The values for a which were reported theorectically and experimentally, varied from one another. They varied between .8 and 1.7. We used Cunningham's correction for this calculation.

We are employing the formulas outlined on pages 514 and 515 (which are very difficult for the translator to transpose). This is well illustrated in figure 1.

The relationship of the amplitudes

Equation 9 shows that the amplitude of the particle remains behind that of the gas the larger the radius and density of the particle becomes and the smaller the viscosity. Especially this is well illustrated in figure 2 where the amplitude conditions are illustrated in terms of various frequencies.

A particle system such as smoke, fog or dust the way they exist in reality is always of non-uniform size. Most of the particles are of a size within .1 and 1.5 μ. Smaller particles, of course, can also be suspended in air. In figure 2, it can be seen that the frequency of the upper-audio range and the lower ultra audio range fall in the region of a negative slope. The size of the particle of the suspended material is from v to v2 (see figure 3) to a frequency of v1. The whole particle is in area A. This means that all particles are swinging with practically the same amplitude which is equal to the amplitude of the gas with frequencies of v1 and v2. The suspended particle is in a transition area, where particles of different size oscillate with different amplitudes. When the frequency is larger than v2, the suspended particle is in an area C, where the particles do not oscillate at all. Correspondingly, the aerosol at constant frequency, say B, may cause an enlarging of the particle thru aggregation go from area A to B to C. This is clearly visable in diagram 3.

Similar conditions and the critical

Another criteria for the relationship of a suspended particle in a

sound field can be derived from similarity relationships. According to ref. 9, the amplitude conditions are regulated according to equation 11 (without a Cunningham correction). If we use a value for X_p/X_g=.8, the point at which the curves have a transition into a flatter exceleration, then the particles will still oscillate computively. During the transition, particles do not oscillate at all. This is illustrated in equation 12, 13 and 14. In figure 2 the line m for the points in the curve for R2V have the value about 10-4.

Microphotography pictures have already been reported by the authors. It was showed that the particles participate in the oscillation according to their size based on formula 9. Based on this, the smallest particles have the largest oscillation amplitude in the transition area while the largest and those aggregated by sound have none. Particles that do not oscillalate move in a spiral and irregular manner. In aerosols of tobacco smoke and ammonia vapor, these spiral forms always appera. However, in fog or parafin oil fog, they could not be observed. Also these particles are under the same influences of the general circulatory movement of the gas in the sound field. With photographic pictures, the oscillation movements can be easily seperated from the circulatory movements of the medium. In this way, of one has an appropriately short exposure time, only the oscillatory movement of the particle is visible. In practice this time, the time of exposure is limited by the experimental conditions. The larger the amplitude, the smaller the light intensity that appear as bright lines of the oscillating particles, and the larger is the velocity of the continuing motion. For the first condition, longer exposure time is required and for the second, shorter exposure times. For high intensity the velocity of the continuing motion was observed to be .3 cm/sec. At an exposure time of .01 second, the particle paths will still appear as white lines. The sound intensity of the microphotography pictures was chosen in such a way that 1/250th of a second would still allow a separation of the moving material and the oscillating particle. The experimental set up for such pictures, namely dark field illumination with a simple shutter, was described already. An improvement in this model was the installation of a mirror H in figure 4, in such a way that incoming and reflected rays were coincident. In this way, an increased light intensity was achieved and the photophorese of the particle diminished which otherwise inactivated the cover glasses G1 and G2 of the observation chamber. In this way, both the pictures in figure 5 were obtained (1/250 sec. on Perutz silver erosin plate).

Figure 5 shows a relatively equal size particle of parafin fog in a sound frequency of 10 KHZ. The radius of all the particles was between .3 and .6 microns. According to figures 2 and 3, this aerosol at 10 KHZ has just gone over the transition area and the particles should be oscillating completely. In fact the majority of the amplitudes had values of 4.8 to 5. Some less bright, i.e. larger particles had amplitudes down to 4.4. If we assume a value of the gas amplitude of 5, then the larger particles of X_p/X_p=.88 (based on figure 2 this corresponds to a size of .8 μ). The oscillation movement of unequal size parafin fog of the same sound amplitude can be seen in figure B. It can be seen that the weakly sized particles swing with full amplitude, the larger ones swing with less amplitude and the very large do not swing at all. (The size of the difference of deviation is obviously not a measure of the size of the particle). In this aerosol, the size of the particle was between .3 and .5 u. Therefore it covers the whole range of the area. Correspondingly the amplitudes varied between 0 and 5 relative measure. These prelimary results give a roughly quantitative substantiation to the results of (1) and (2).

The knowledge of the relationship between sound amplitude and particle amplitude is important for various physical experimental designs. We already alluded to this early in the determination of sound amplitude with microphotography. Furthermore, important information can be derived from the opposing influence of the aerosol and the sound field. This means the deltas of the field by the enclosed particles and the deltas of the sound field by the aerosol respectively. The starting point for our studies is the delta that is caused in the aerosol by the rapid acoustic coagulation. We will discuss this in greater detail and more thoroughly later. For now it will be of value to quickly discuss the simplified formula of the process of sound absorption.

The acoustical absorption is expressed (1) as a loss of the actual carrier. The gas and (2) as a loss of the particles in the transitional area of the particle and the gas. The acoustical absorption in the carrier will not be taken into account in this consideration. Very elegant reports have appeared previously by Rayleigh and Kasterin on the acoustical loss of the particles in the carrier. A further mathematical consideration has been put forth by Ostwald and Mache in order to illustrate the problem of acoustical absorption in fogs. An important aspect of this is the energy loss of the individual particles as they rule together in the gas phase. The works of these authors touch on the dependence of the variables of the various formulas in a very elementary fashion. In this connection the upper and lower acoustical areas are also classified as transition areas for the aerosols. It is obvious that the degree of participation of the various particles in oscillation is strictly dependent on the loss of acoustical intensity when the particles interact with the gas. For our discussion we will concentrate on an aerosol particle suspended in a gas. The velocity difference between gas and particle is to be derived from equation 7 and 10. Further mathematical treatment of the interaction between particle and gas can be derived from equations 15, 16, 17, 18 and 19. The second factor of equation 19 is function of particle radius and frequency and is dependent on both. The size of the absorption coefficient is air is dependent on the particle radii in air and can be ascertained from figure 6. λ^*/c is chosen as the ordinant. The larger the particle radius the smaller the frequency since the larger particles remain behind the gas oscillation at lower frequencies. When the particle radii become smaller then the slope begins to increase toward higher frequencies. If the degree of dispersion of a fog is high at high frequencies, the acoustical absorbance caused by particle interaction assumes very high values. The fact that acoustical absorption actually assumes very high values was already shown in experiments of Aulthing and Holtzman for tobacco smoke, even though a quantitative comparison could not be carried out because of the uncertainty in the experimental conditions employed. We do not intend to go into this aspect more deeply in this paper since it is only necessary to show that the chosen area is typical for transition area.

On the theory of the acoustical coagulation

The starting point of our theorectical discussion is based on the phenomena of the aggregation of particles in a sound field. A fruitful discussion of this effect has already been presented in other discussions. In order to get a quantitative calculation of coagulation in acoustical fields, many difficulties arise even if one assumes that the calculations and experimental results of the individual single particles are known. Primarily the difficulties are concerned with the coagulation mechanism is not uniform and the aggregation is dependent upon various factors acting

simultaneously. It is immediately clear that all the factors of coagulation must be enhanced in order to release the attractive force between the suspended particles. Such processes can be of a hydrodynamic nature as described by Loenig and Bierknes. Funnel formation which surrounds the particles during this process must also be considered; also pulsations and deformation oscillations. For all these effects the participation of the particles in the oscillation is of great importance. Usually all interactions of suspended particles in an oscillation result in coagulation and for this reason all such processes must be considered for an explanation of acoustical coagulation. This probability is obviously enhanced for certain processes which cause an irregular oscillation of the particle. Since an aerosol is always present as polydispersed system, such irregular oscillations due to the different sized of the particle amplitudes appear in the transition area. The coagulation caused in this way is designated as orthokinetic instead of annexation in the sense described by Weigner et al. Weigner et al. in their work apparently designated movement of particles in fluids as orthokinetic and parikinetic. The parikinetic mode which is affected by irregular Brownian movement can be left out in our consideration since its velocity is small compared to acoustical coagulation. The orthokinetic coagulation should, according to Weigner, appear in certain areas of force so that the particles of various size receive various velocities. This in turn causes an increased probability of collision between the dispersed particles. In the following we mean only the coagulation that was caused by irregular amplitude distribution. This is in reference to the orthokinetic collision in an acoustical sound field. We do not consider among the possibilities an arthokinetic coagulation. The process of aggregation which is derived from all these processes taken together is very involved and little hope exists that experimental results will be in agreement with theoretical observations. One can seperate the individual effects from one another and derive significant information in this way. This is briefly outlined in the next paragraph for orthokinetic coagulation and for the hydrodynamic forces.

An appraisal of the part that the orthokinetic coagulation plays we presented in our work on the theory acoustical coagulations. It rests on the following premises. The simplifying assumption is made that a certain concentration of non-oscillating large particles and another concentration of completely swinging smaller particles are present. All intermediate steps are ignored. In other words, the oscillations of the small particles are looked at independently of the large particles. In this way one can determine an aggregation area around each large particle in which it will not come in contact with the oscillating small particles. This aggregation volume is dependent on the size of the large and small particles and on the oscillation amplitudes. The assumption that the oscillations of the small particles is not disturbed by the large particles is in reality not completely true since the particles of the moving gas follow the large particles even though only partially due to their large inertia. With this simplification, the aggregation volume was estimated too large. In the opposite direction, the other factors, which we have ignored act. The first of these, the growth of the aggregation volume is not accounted for and secondly, orthokinetic collisions are already playing a part in the hydrodynamic forces. The aggregations volume moves with the large particles area and in this way acts as an aggregations nucleus until it has settled. The mean velocity of this movement is designated as W_a and is schematically represented in figure 1, p. 525. Z represents the concentration of small particles and Zo its stationary concentration. Z is

large particles; $\bar{w}$ is the mean velocity; H the oscillations amplitude and T time. This can be rearranged to formula 2, p 525. In figure 7 the diagram shows the dependence of half-time "t" on the concentration of the large particles. Value for medium velocity was obtained experimentally, and varied widely. Log Z is abscissa and tau is the ordinant. The curves are valid for oscillation amplitudes of 40-200 u. Sigma was 3 µ for solid curves and for dashed lines 2.2 µ. These results cannot be transferred to every actual aerosol. One must also consider that the no. used in this calculation vary widely in actuality so that the actual results are only real in the order of magnitude. In the model fog, the actual properties of a real fog were considered so that the orthokinetic coagulation in the chosen frequency area plays a role and is intimately involved in the higher concentrations of the total aggregation.

The quantitative part the hydrodynamic forces play in coagulation

This is also a very difficult calculation. We have chosen only to discuss the time in which equally large particles move in a distance $\Delta 2V$. This is shown in formula on page 526. The difference in velocity ΔV is defined by equation 7. The size of the dependence of the large particle needs a very accurate determination of the material of the suspended particles as well as a definite position of where the particles are. Even the possibility to work with an isosuspended material does not surmount the difficulties since the suspended material becomes aggregated in the acoustical field. The attractive forces are proportional to the curve of the radius. The is in agreement with work we have published earlier (1). One can calculate the time within which the particles approach each other to a certain distance in order to gain an insight under which conditions the hydrodynamic forces play a major role. The following calculation is done for the case where a particle moves 90% to the direction of the sound and the attractive movements are not disturbed by the oscillation movements of the gas and the whole process behaves according to Stoke's Law of Resistance. The intensity of the sound was assumed to be equal to all frequencies. Table 1 shows the corresponding time of both particles whose density was assumed to be 1. The starting distance was 17 µ. The differences in the velocity between the particles and the gas were taken from figure 2. The upper values were for lower sound energy and the lower values, in parentheses, were for higher sound energy.

The error range obtained when using the middle values discribed above as well as the considerable limitation placed on the assumption that the particles are of equal size was already discussed above. Despite this one can conclude that the coagulation simply by hydrodynamic forces only becomes effective at high frequencies and large particles.

The part that the orthokinetic coagulation and the hydrodynamic forces play on the overall aggregation can be summarized as follows. In the transition area orthokinetic coagulation occurs due to nonuniformity in the aerosol. This appears to be important in this area for the mechanism of coagulation. Its effect is enlarged by the hydrodynamic forces between particles. At higher frequencies the acoustic frequency is lowered and then the acoustical coagulation takes over and the hydrodynamic forces come to the foreground. The sound absorption increases strongly with higher frequency and the distance sound waves can travel becomes less. The differences that appeared in the theoretical work on coagulation caused rise to study this in an experimental way in greater detail. A difficulty that has not yet been mentioned is the problem of coagulation of aggregated external dust. The following comment may suffice about this.

Structure of the aggregated particle

Suspended material whose dispersed phase is liquid flow together in spherical forms during aggregation. On the other hand, with dust very loose forms were observed. With acoustical aggregation a very rapid aggregation velocity can be reached in order to get particle enlargement. This happens before the particles settle out. The flaculent structure of dust is very diffuse. Figure 8 shows a picture of dust before and after aggregation on glass. Whether such structures appear due to the properties of the particles or due to special properties of aggregation cannot yet be defined. The aggregated aerosol particles can be seen in suspension under an electron microscope and for larger aggregates one can even observe these with the naked eye. The position of those particles which seem to sparkle in the light; alter continually in relation to the rotation component of Brownian movement. The sparkle effect is in all cases evidented for the presence of non spherical particles. In the acoustical and electrical alternating field dust particles aggregate very clearly. This also happens in aggregated tobacco smoke. Because of the high water content in tobacco smoke it was generally thought to be represented by spherical droplets. The behavior in a sound field as well as on microscopy pictures of an acoustical aggregated and sedemented tobacco smoke, we have already presented in previous publications. In these spherical particles a definate form can be observed.

Electric fields can affect the sparkling of the particles that are suspended in the medium especially if they are strong enough to hold the particles in a specified position. We used the sound field itself for this purpose at low sound intensity so that the particles did not aggregate. We also used an alternating current. The direction in which the particles directed themselves could be predicted in simple cases. Ferndlich et al. (2) studied needle and thin sheets of hydrosol particles in the liquid stream. Other authors have also investigated hydrosal particles in electric alter-current (3). In this way the particles orient themselves according to their longitudeinal axis. A more complicatdd case is represented when sound fields are used in these studies. The delta of the intensity of the single particles due to their orientation is represented by the sun in a suspended particle so that in certain cases a darkening or an illumination occurs in the tindle effect. Even in the dust there are regions where optical intensity in certain field strengths can be observed. Black used ammonia vapor and showed conclusively an enhanced intensity in an electrical field. In aggregated NH_3 vapor as well as tobacco smoke will also confirmed a marked intensity in an electrical field and as expected parafin fogs did not show the effect.

In order to avoid subject of errors of expermentation, we concentrated the tindel light on the chamber of a photocell. Because of the aggregation effect in the electrical field, the scattered light intensity decreases. When the electrical field was shut off the experiment failed. The decrease in the scattered light intensity decreased by 20%. When the light was turned on again the intensity reappeared, however, in the case of tobacco smoke the previous intensity was not reached again. We assume this is due to the fluid tobacco smoke particles form droplets and aggregated while they were suspended in the turned off electrical field.

In order to minimize the light jump during switching on and off, the light measuring on the galvanometer was taken up onto a light sensitive paper. The galvanometer used had a swinging amplitude of a 50th of a second. In the diagram of figure 9, the ordenates represents the electrical light and intensity of the abscissa time. One can clearly see that the straight energy out of the relationship occurs very rapidly. The time needed is dependent on the moment of inertia, even in very small NH3 vapor particles which remain after the larger particles have aggregated the increased intensity was observed. The extent of the particles in the sound field was observed. Especially difficult was that the particles remain clearly seperated according to size and frequency. Needle and disc-like larger aggregates which clearly surpass the critical data did not continue to oscillate. This followed our previous experiment with theorectical data with its longitudinal axis. As soon as the particles oscillate, all other things follow the normal rules exactly. It is to be assumed from this that they orient themselves in the direction of acoustical flow. In the acoustical transition area where there particles are partically oscillating the position is undetermined.

Summary

1. A simple formula was derived which permitted the relationship between particle amplitude and gas amplitude can be understood and to be able to decieve the difference between particle amplitude and that of gas.

2. From the former it can be seen that for every particle size a definite amplitude exists in which the particles are oscillating constantly in the carrier.

3. When this frequency is surpassed the particle amplitude lags and finally approaches zero. For every aerosol which is more or less a frequency area, (acoustical area) can be reached in which the particles of various size oscillate with varying amplitudes.

4. For a specified aerosol R^2V is applicable where frequency = V and particle radii = R. For the same values in this expression the particles as compared to the amplitude behave similarly.

5. Short time microphotographic pictures (0 1/250th of second) of a polydisperse suspended material in the acoustical transition area and a suspended particle external to the transition area give agreement with theoretical results.

6. It was shown in an experiment of sound absorption that the acoustical transition area must play a part in other instances. As soon as the frequency becomes high, i.e. up to where the particles oscillate, sound losses occur due to the rubbing together of the suspending gas and the suspended particles. From the formulas given above, it can be shown in an elementary way that the part that the sound absorption plays is dependent on the frequency.

7. A theoretical consideration of acoustical coagulation meets many difficulties. It can be shown that in the acoustical transition area there is a high probability of collision between the particles. This coagulation was designated arthokinetic coagulation. Hydrodynamic forces are also involved and especially at high frequency.

8. In several preliminary experiments we investigated the structure of acoustically aggregated dust. The flaculent structure of aggregated particles was determined by microscopy. When the particles were oriented in a field electrical or otherwise, a markedly enhanced brightening occured in the tindal light. This whole phenomena measuring the intensity of the tindal light was done with a galvanometer and a photocell. The experimental part of this was done with instruments of the Helmholtz Corporation.

$$W = 6\pi r \eta \Delta v \left(1 + A\frac{l}{r}\right) \cdot$$

$$b = \frac{1}{6\pi\eta r}\left(1 + A\frac{l}{r}\right),$$

$$W = \frac{\Delta v}{b} \cdot$$

Equation 1.

$$\begin{aligned} x_e &= X_e \sin \omega t, \\ v_e &= X_e \omega \cdot \cos \omega t = V_e \cos \omega t. \end{aligned}$$

Equation 2.

$$m\ddot{x} = \frac{1}{b}(V_e \cos \omega t - \dot{x}).$$

Equation 3.

$$x = \frac{B}{\omega}\sin(\omega t - \varphi) + \frac{B^2 m b}{V_g} e^{-\frac{t}{b \cdot m}},$$

wo

$$B = \frac{V_g}{\sqrt{(m\,\omega\,b)^2 + 1}} \quad \text{und} \quad \operatorname{tg}\varphi = m\,\omega\,b,$$

also

$$B = V_g \cos\varphi$$

(Teilchenmasse $m = \frac{1}{3} \cdot \pi \cdot r^3 \cdot d$).

Equation 4.

$$x_p = \frac{X_r}{\sqrt{\left(\frac{4\pi d \cdot r^2 \nu}{9\eta F}\right)^2 + 1}} \sin(\omega t - \varphi).$$

Equation 5.

$$X_p = \frac{X_r}{\sqrt{\left(\frac{4\pi d r^2 \nu}{9\eta F}\right)^2 + 1}}.$$

Equation 6.

$$\Delta r = r_g - r_p = a\,[X_g \cos\omega t - X_p \cos(\omega t - \varphi)].$$

$$\Delta r = V_g \sqrt{1 - 2\cos\varphi \frac{X_p}{X_g} + \left(\frac{X_p}{X_g}\right)^2} \cos(\omega t + \alpha).$$

Equation 7.

$$\vartheta = V_g \sqrt{1 - 2\cos\varphi \frac{X_p}{X_g} + \left(\frac{X_p}{X_g}\right)^2}.$$

Equation 8

$$\frac{X_p}{X_g} = \frac{1}{\sqrt{\left(\frac{4\pi d r^2 \nu}{9\eta \cdot F}\right)^2 + 1}}.$$

Equation 9.

$$\frac{X_p}{X_g} = \cos\varphi, \quad \frac{\vartheta}{V_g} = \sin\varphi.$$

Equation 10.

$$\frac{d^2 y}{\tau} = Z.$$

Equation 11.

$$0{,}3 = \sqrt{\frac{1}{K \cdot Z_0^2 + 1}} \quad (K = \text{Konstante}).$$

Equation 12.

Es ist dann

$$Z_0 = 0{,}54\ [\text{sec}^2, \text{F}, \text{f}].$$

Equation 13.

$$\text{F}^2 \cdot \text{f} = \text{etwa } 10^{-4}\ \text{cm}^2/\text{sec}.$$

Equation 14.

$$K = -\frac{1}{\zeta} \cdot \Delta c,$$
$$= -\frac{1}{b}\,\vartheta \cos\omega t.$$

Equation 15.

Für die durch Reibung absorbierte Energie folgt:

$$\int_0^s K\,ds = \int_0^t -\frac{1}{b}\,\vartheta^2 \cos^2\omega t \cdot dt.$$

$$dE = -\frac{1}{b}\,\vartheta^2 \left[\frac{t}{2} + \frac{1}{4\omega}\sin 2\omega t\right].$$

Das periodische Glied ist zu vernachlässigen. Unter Berücksichtigung von (10) folgt

Equation 16.

$$dE = -\frac{t}{b} \cdot \frac{V_g^2}{5} \cdot \sin^2\varphi.$$

$$E = -\frac{V_s^2}{2} l \varrho u.$$

Hierin bedeutet u die Schallgeschwindigkeit und ϱ die Dichte des Mediums. Die Teilchenkonzentration sei n. Die der ebenen Welle beim Fortschreiten über die Strecke dx entzogene Energie ist:

$$dE = -\frac{1}{b\varrho u} \cdot nE \sin^2 \varphi \, dx. \qquad \text{Equation 17.}$$

$$E = E_0 e^{-\frac{n}{\varrho u b} \sin^2 \varphi \cdot x}. \qquad \text{Equation 18.}$$

$$\alpha^0 = \frac{c}{\varrho u} \cdot \frac{\sin^2 \varphi}{b \cdot m}, \qquad \text{Equation 19.}$$

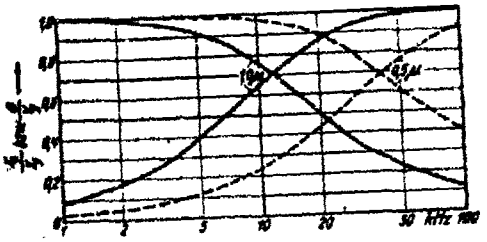


Fig. 1. X_p/X_g und ϑ/V_g in Abhängigkeit von der Frequenz für Teilchenradien von 1 μ und 0,5 μ.

Figure 1.

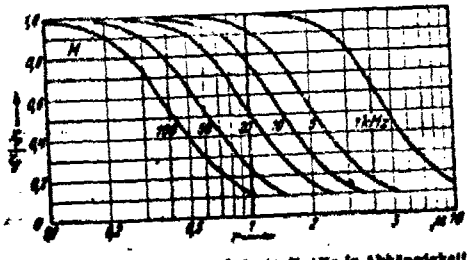


Fig. 2. Das Amplitudenverhältnis X_p/X_g in Abhängigkeit vom Teilchenradius für verschiedene Frequenzen.

Figure 2.

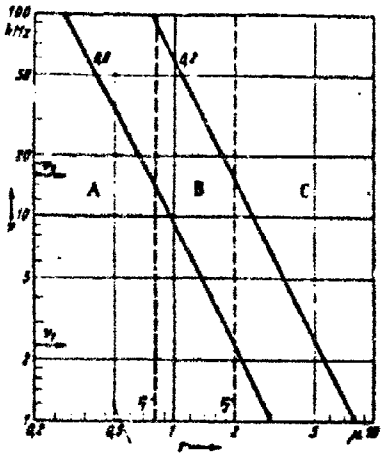


Fig. 3. Abgrenzung des akustischen Übergangsgebietes *B* vom Gebiet *A* des vollständigen Mitschwingens und vom Gebiet *C* des Nicht-Mitschwingens.

Figure 3.

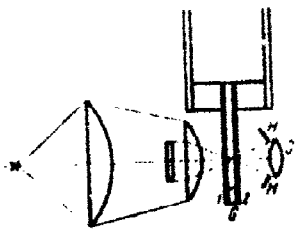


Fig. 4. Dunkelfeldbeleuchtung mit Zentralabblendung. *H* = Hohlspiegel.

Figure 4.

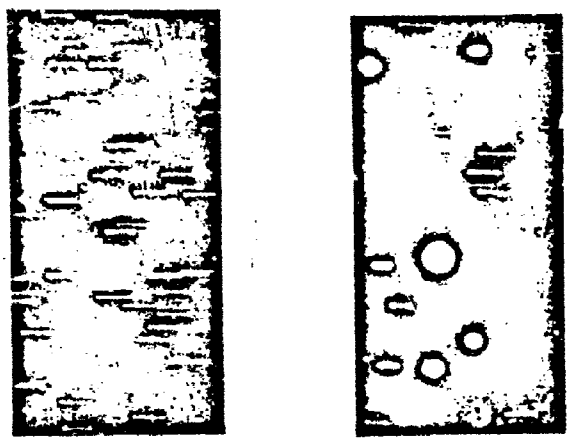


Fig. 5. Mikroaufnahmen schwingender Partikel.
a) unterhalb, b) innerhalb des akustischen Übergangsgebietes. Vergrößerung: 80 mal.

Figure 5.

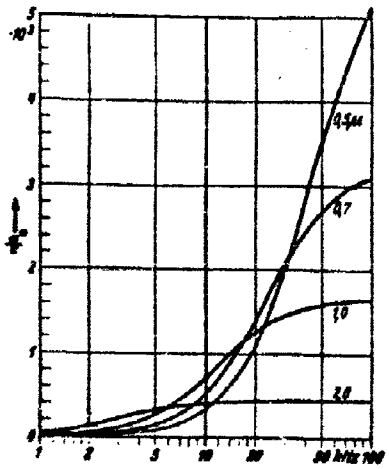


Fig. 6. α^*/c (α^* = Schallabsorptionskoeffizient, c = Gewichtskonzentration des Nebels) in Abhängigkeit von der Frequenz für verschiedene Teilchenradien.

Figure 6.

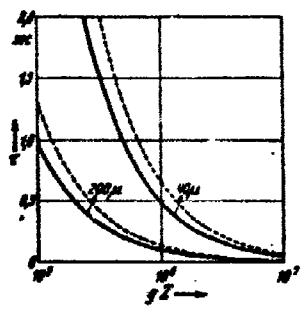
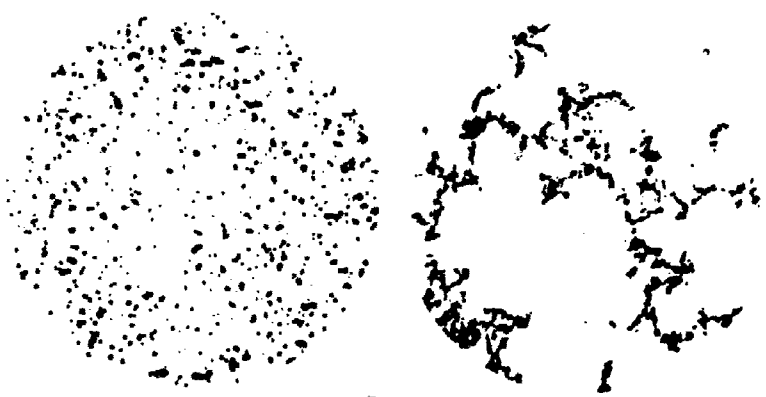


Fig. 7. Halbwertszeit τ der orthokinetischen Koagulation in Abhängigkeit von der Konzentration der großen Teilchen.

Figure 7.



a) Sedimentierter unbeschallter Staub etwa 800fach.

Fig. 8.

b) Sedimentierter beschallter Staub etwa 800fach.

Figure 8.

Figure 9.

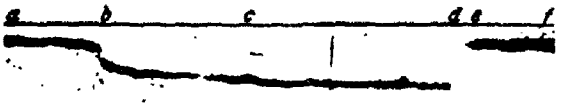


Fig. 9. Registrierung der Verdunkelung und Aufhellung des Tyndall-Lichtes beim Ab- und Einschalten des Feldes.

Table 1.

Tabelle 1.

Frequenz	t_0 für $R = 0{,}5\,\mu$	t_0 für $R = 1\,\mu$
1 kHz	$4{,}8 \cdot 10^9$ sec ($1{,}9 \cdot 10^4$)	$8 \cdot 10^8$ sec ($3 \cdot 10^5$)
10 kHz	$1{,}6 \cdot 10^7$ ($7 \cdot 10^6$)	$4{,}5 \cdot 10^3$ ($1{,}8 \cdot 10^2$)
100 kHz	$2{,}3 \cdot 10^4$ ($9 \cdot 10^3$)	2,7 $\cdot 10^2$ (10,8)