



## The Measurement of the ESA Effect

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### Abstract

The note is an introduction to how the ESA (Electrokinetic Sonic Amplitude) effect is measured. This effect refers to the sound wave generated when an alternating electric field is applied to a colloidal suspension.

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## 1 Introduction

The electroacoustic effect in which we are interested is called the ESA effect (short for *electrokinetic sonic amplitude*, the name given to it by its discoverers in the 1980s). It refers to the sound wave generated when an alternating electric field is applied to a colloidal suspension.

To measure the ESA effect the sample is placed in a cell containing two electrodes, as shown in Figure 1. The electric field (of the order 100 volt/cm) is applied to the two electrodes at a very high frequency (in the range 0.2 to 20 MHz.) The colloidal particles are normally electrically charged. (See the Colloidal Dynamics Electroacoustics Tutorial No. 3 for more on this.)

The electric field causes the particles to oscillate backwards and forwards at the same frequency as the field. Throughout most of the suspension those oscillations cancel one another out, but near the electrodes the cancellation does not occur and from there a sound wave is generated.

The sound wave moves out of the suspension and along the delay rod (a piece of glass or plastic or metal) until it hits the transducer, which is a piece of specially prepared plastic film or a special sort of crystal. The sound wave causes the transducer to vibrate and this in turn generates a voltage on either side of the transducer. It is this voltage which allows us to determine the characteristics of the sound wave. What we need to know is the relation between the voltage across the transducer and the initial voltage applied across the cell.

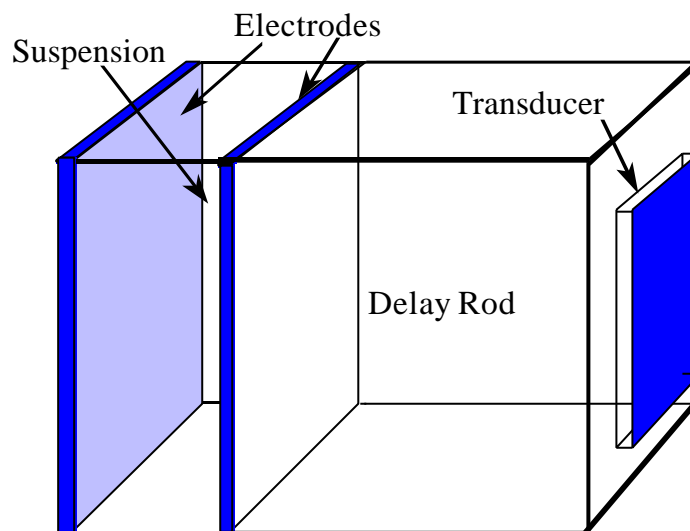


FIGURE 1 THE MINIMAL ARRANGEMENT FOR MEASURING THE ELECTROACOUSTIC EFFECT.

THE ESA EFFECT IS MEASURED BY APPLYING A FIELD TO THE ELECTRODES AND LISTENING FOR THE SOUND IN THE TRANSDUCER. THE CVP EFFECT COULD, IN PRINCIPLE, BE MEASURED BY APPLYING AN A.C. VOLTAGE TO THE TRANSDUCER, PRODUCING A SOUND WAVE, AND THEN MEASURING THE RESULTING VOLTAGE ACROSS THE ELECTRODES.

## 2 Why the Delay Rod?

The delay rod is there to enable us to hear the tiny sound signal without interference. As soon as the electric field is applied to the cell, the very sensitive transducer 'hears' a signal of the same frequency, generated by what is called 'cross talk'. That signal is so strong that it would drown out the tiny signal from the colloid. The solution to that problem is to apply the electric field in the form of a short pulse (lasting about 20 microseconds).

The length of the delay rod is chosen so that it takes more than 20 microseconds for the sound wave to travel down to the transducer. In that way we ensure that the transducer is quiet and ready to receive the sound wave.

In fact we collect two signals: one from the near electrode and another from the far electrode, which has also had to travel through the suspension.

## 3 The Nature of the Signal

At the frequencies used in electroacoustics it turns out that the particles can move at almost the same velocity as they do in a d.c. field, but not quite.

As the frequency is increased from the minimum to the maximum value the particles tend to fall further behind. They travel more slowly than they do in a d.c. field and *they also lag behind the field*. As the field changes direction in each cycle, it takes a little time for the particle to slow down, stop, and then go back in the opposite direction. That is due to the inertia of the particle and the effect becomes larger as the size of the particle increases.

The time delay is registered as a *phase lag* between the electric field and the particle motion (see Figure 2.).

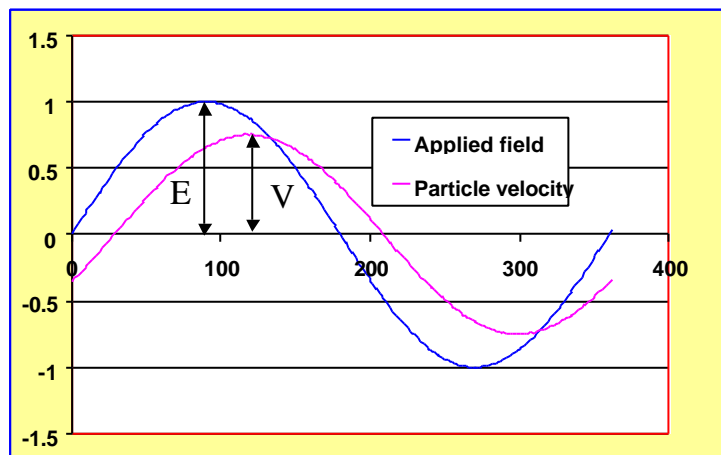


FIGURE 2: THE PARTICLE VELOCITY ( $V$ ) IN THIS CASE LAGS BEHIND THE FIELD ( $E$ ) BY ABOUT 30 DEGREES.

To specify the relation between the applied field and the resulting response we need to specify both the relative magnitude of the signals and the phase lag between them. Both quantities are important for estimating the size of the particles. Having both the magnitude and the phase effect to work on makes estimation of the size distribution a great deal more effective than working with only the magnitude effect.

The zeta potential usually only affects the magnitude of the signal but if it is very large it will also affect the phase and that can be of crucial importance.

The quantity we are looking for is the *dynamic mobility* of the particles, which is the high frequency analogue of the d.c. mobility. Its magnitude is the ratio of the particle velocity ( $V$ ) to the field strength ( $E$ ). To specify it completely we need also to specify its phase angle. Such a quantity (which requires two numbers to specify it) is called a complex number. That simply means that it is a particular sort of number pair, which we will examine in more detail later (in subsequent Electroacoustics Applications notes).

At 0.2 MHz, even a 1 micron particle has little trouble keeping up with the field. So its mobility magnitude is close to its d.c. mobility and it has nearly zero phase angle. As the frequency rises towards 20 MHz, the magnitude will fall and the phase angle will increase towards  $45^\circ$ . A 10 micron particle will already have a large phase angle at the lowest frequency, and will have a mobility magnitude much less than its d.c. value.

A very small particle ( $< 0.1$  micron) will be able to keep up with the field at all but the highest frequencies and will have almost zero phase angle even at the highest frequencies.