



Welcome to Vibrationdata.com

Acoustics • Shock • Vibration • Signal Processing

June 2002 Newsletter

Yá'át'ééh

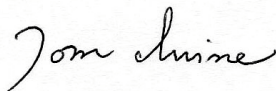
Bubble Acoustics is the topic of the lead article for this month's issue. Underwater bubbles have a number of fascinating acoustical properties. The understanding of these effects helped scientists to determine that the Submarine Kursk sank due to an internal explosion, as first reported in the October 2001 Newsletter.

Molecular Vibration is the second topic. Molecules have vibration modes similar to those of spring-mass systems. Molecular vibration frequencies are extremely high, however. A carbon monoxide molecule has a frequency of 64.29 tetrahertz, for example.

Again, I encourage readers to submit their own articles or items of interest to this newsletter.

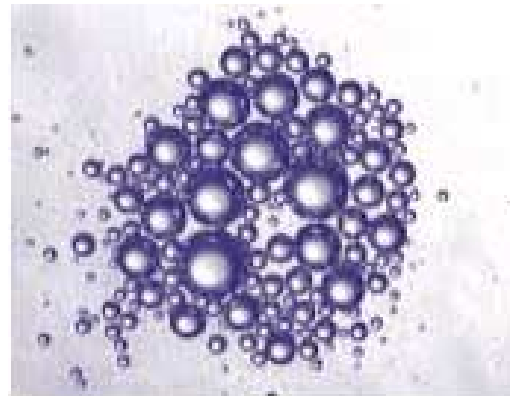
Readers are also welcome to freely distribute the newsletter among their colleagues.

Sincerely,

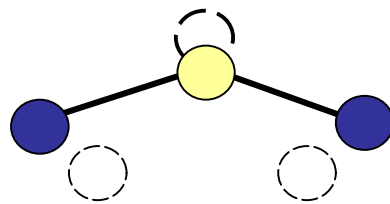


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Feature Articles



Bubble Acoustics page 3



Molecular Vibration page 8



Welcome to Vibrationdata Consulting Services

Vibrationdata specializes in acoustics, shock, vibration, signal processing, and modal testing. The following services are offered within these specialties:

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2. Data analysis and report writing
3. Custom software development and training
4. Test planning and support

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Bubble Acoustics by Tom Irvine



Figure 1-1. Gas bubbles rising from shallow hydrothermal vents, Milos, Aegean Sea (GEOMAR)

Introduction

Bubbles produce much of the noise that accompanies a waterfall, a rushing stream, or liquid pouring into a glass.

Natural Sources in the Ocean

Methane and carbon dioxide gases escape as bubbles through vents in the sea floor, as shown in Figure 1-1.

In addition, breaking waves cause atmospheric gases to mix with the sea, creating air bubbles near the water surface.

Raindrops also create air bubbles as they impact the ocean surface. The characteristics of these bubbles are discussed later in this report.

Cavitation

A manmade source of bubble is cavitation. This is an effect whereby water vapor bubbles form in the wake of a ship's propeller. These bubble form and collapse rapidly. Cavitation may be considered as a localized boiling effect. Cavitation is an undesirable effect because the collapsing bubble cause damage to the propeller blades. Small, fast running propellers with numerous blades are much more prone to

cavitation than slow-running, larger, propellers with fewer blades.

Natural Frequency

A bubble is analogous to a simple spring mass system. The compressible gas in the bubble forms the spring. The fluid surrounding the bubble provides the mass.

The bubble's first mode shape corresponds to an alternating compression and expansion of the gas in the bubble. The displacement is symmetrical in the radial direction.

The natural frequency f_n of a spherical bubble is

$$f_n = \frac{1}{2\pi R_o \rho^{1/2}} \left[3kP_o - \frac{2\sigma}{R_o} \right]^{1/2} \quad (1.1)$$

where

P_o = absolute liquid pressure

R_o = mean radius of the bubble

k = polytropic constant of the gas in the bubble

σ = surface tension constant

ρ = mass density of the liquid surrounding the bubble

Equation (1.1) is taken from Reference 1-1. Minnaert derived this equation in 1933.

Surface Tension

The surface tension constant for air/water at 20°C is: $\sigma = 7.27 (10^{-2})$ N/m. The effect of the surface tension on frequency diminishes as the radius becomes larger.

Density

Density values for selected liquids are given in Table 1-1.

Table 1-1. Liquid Density		
Liquids	Temp. (°C)	Density (kg/m ³)
Water (fresh)	20	998
Water (sea)	13	1026
Alcohol (ethyl)	20	790
Mercury	20	13,600

Polytropic Constant

The dimensionless polytropic constant k can vary within the range

$$1 \leq k \leq \gamma$$

Note that γ is the ratio of specific heat of the gas in the cavity at constant pressure to that at the constant volume. $\gamma=1.4$ for air.

The value $k = 1$ corresponds to an isothermal process where heat can transfer into an out of the bubble rapidly enough to keep the gas at a constant temperature. Very small bubbles tend to behave in an isothermal manner.

The value $k = \gamma$ corresponds to an adiabatic process whereby no heat energy can transfer into or out of the bubble cavity. Large bubble tends to behave in an adiabatic manner.

Absolute Liquid Pressure

The pressure P_0 at a given depth h in a static liquid is a result the weight of the liquid acting on a unit area at that depth plus any pressure acting on the surface of the liquid.

$$P_0 = P_{atm} + \rho g h \quad (1.2)$$

Raindrop Impact

The bubble noise produced by a raindrop varies according to the size of the raindrop.

A tiny rain droplet has a diameter of about 300 microns (0.01 inch). A very large raindrop may have a diameter greater than 5 millimeters (0.20 inch).

The acoustics effects are shown in Table 1-2 as a function of raindrop size. There are two noise mechanisms. The first is the noise made at impact. The second is the bubble oscillation noise.

Small Drops

Small raindrops, less than 1.2 mm diameter, are present in almost all types of rainfall, including light drizzle.

Small raindrops are remarkably loud. The impact component of their splash is very quiet. The bubble formation, however, produced intense underwater sound. The frequency range is 13 kHz to 25 kHz.

Note that the audible frequency range for the average human extends from about 20 Hz to 16 kHz. Thus, most of the bubble noise is above the upper frequency limit of human hearing.

A series of images representing the formation of a bubble by a small drop is shown in Figure 1-2.

Medium Drops

Drops of medium size, 1.2-2.0 mm diameter, do not trap bubbles underwater. Thus, they are relatively quiet.

The only acoustic signal from these drops is a weak impact sound spread over a wide frequency band.

Large Drops

For large raindrops, greater than 2.0 mm diameter, the splash becomes energetic enough

that a wide range of bubble sizes are trapped underwater during the splash. These bubbles produce a loud sound that includes relatively low frequencies, beginning at 1 kHz.

For very large raindrops, the splat of the impact is also very loud with the sound spread over a wide frequency range, 1 kHz to 50 kHz.

Drop Size	Diameter (mm)	Sound Source	Frequency Range (kHz)	Splash Character
Tiny	< 0.8	silent	-	gentle
Small	0.8–1.2	loud bubble	13–25	gentle, with bubble every splash
Medium	1.2–2.0	weak impact	1–30	gentle, no bubbles
Large	2.0–3.5	impact, loud bubbles	1–35	turbulent, irregular bubble entrainment
Very Large	> 3.5	loud impact, loud bubbles	1–50	turbulent, irregular bubble entrainment, penetrating jet

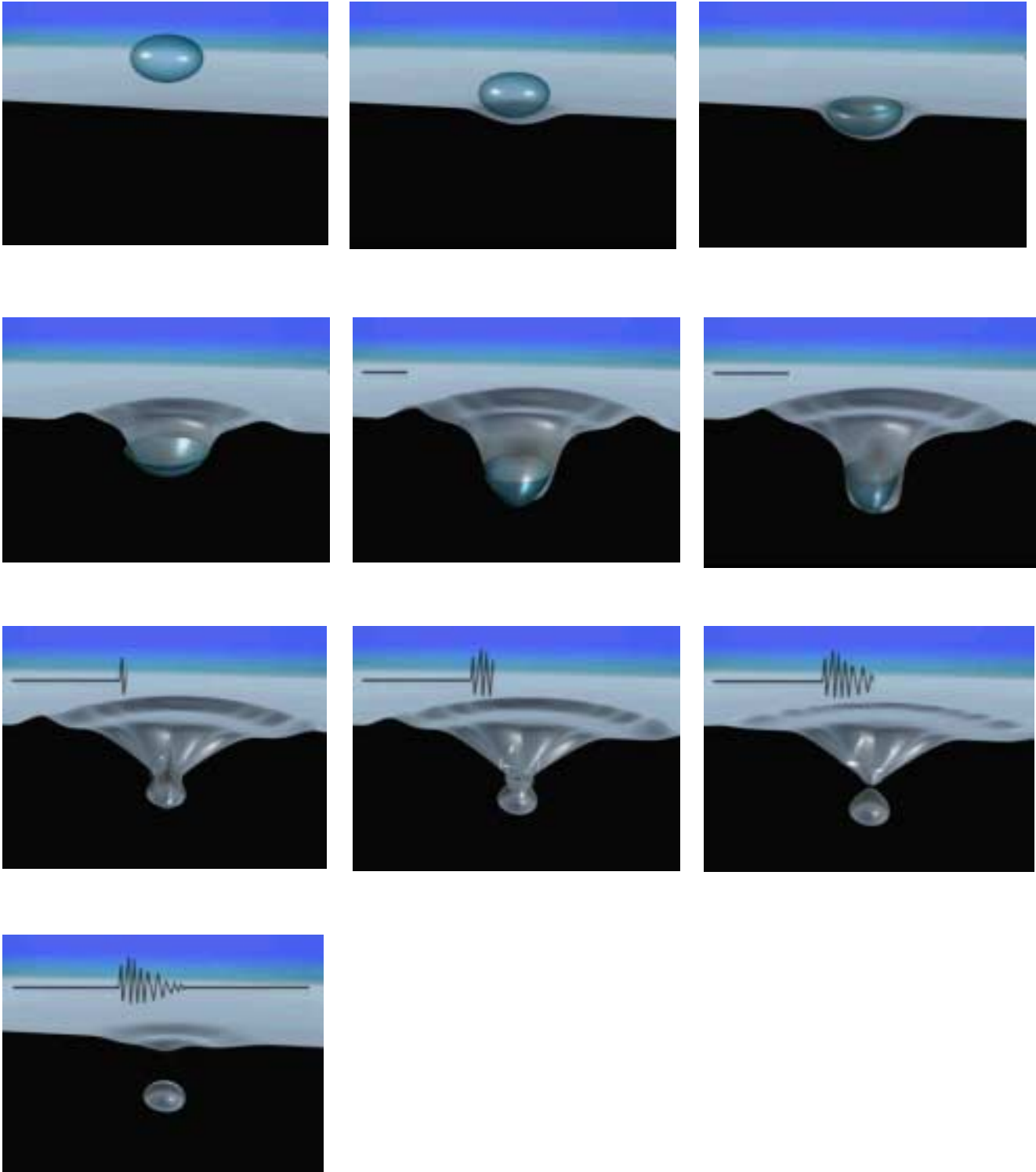


Figure 1-2. Bubble Formation by a Small Raindrop
The images are taken from Reference 1-2.

Underwater Explosions

Raindrops produce bubble with very high natural frequencies. Much of the resulting sound energy is above the upper frequency limit of human hearing. In contrast, underwater explosions generate large bubbles, with a noise spectrum below the lower frequency limit of hearing.

A bubble pulse is generated when hot gases are created in an explosion. This bubble rises rapidly and oscillates. The oscillation depends on the size of the explosion and the depth of the detonation. Seismologists are well acquainted with bubble pulses from years of experience in offshore-oil prospecting and nuclear-bomb testing.

The Kursk submarine experienced an internal explosion, as reported in the October 2001

Vibrationdata Newsletter. Seismic sensors recorded the effects of the explosion. The explosion generated bubble pulses.

The spectral peaks in Figure 1-3 are due to the bubble pulse and water column reverberations from the Kursk explosion, as indicated. The bubble pulse peaks are separated by 1.45 Hz.

The broad spectral peak at 9 Hz corresponds to water column reverberation. The equivalent period is 0.11 seconds. The speed of sound in salt water is approximately 1500 meters/sec. Thus, the distance per cycle is 165 meters. The half-cycle distance is 85 meters. This distance is similar to the report that the Kursk sunk to a depth of 100 meters.

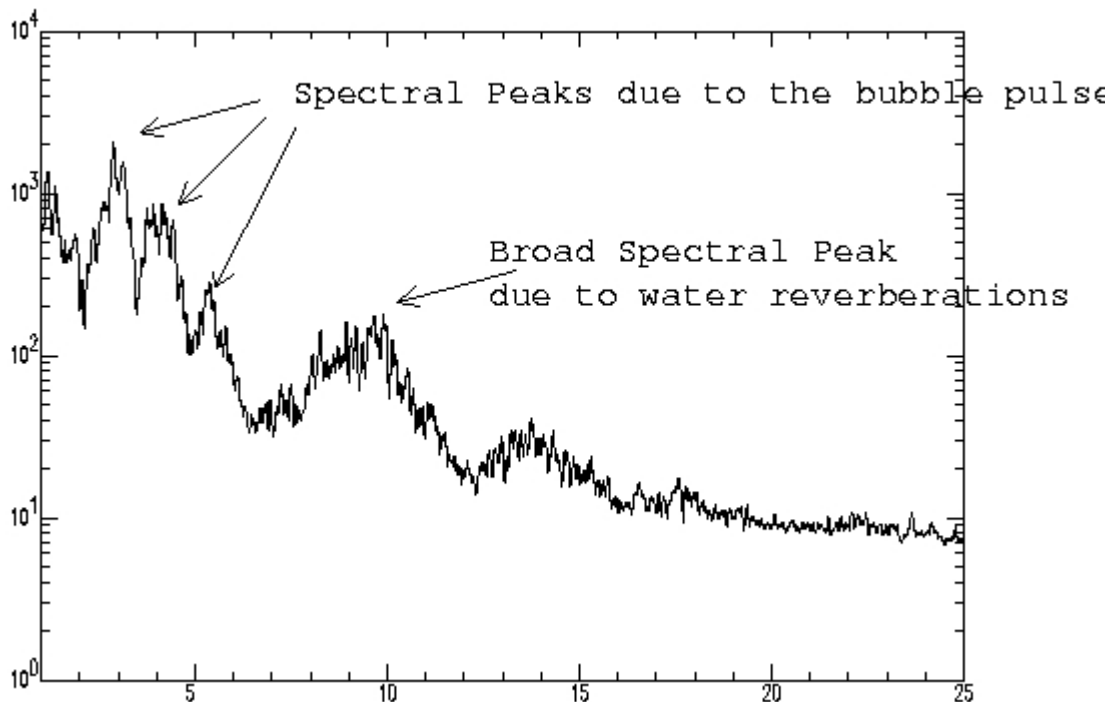


Figure 1-3. Spectral Function of the Main Tremor from the Kursk Explosion

The spectral data is taken from the IRIS station KEVO in Finland.

References

- 1-1. R. Blevins, Formulas for Natural Frequency and Mode Shape, Krieger, Malabar, Florida, 1979.
- 1-2. <http://earthobservatory.nasa.gov/Study/Rain/rain.html>

Molecular Vibration by Tom Irvine

Introduction

A molecule may undergo several types of motion.

First, the molecule as a whole may move through space in some arbitrary direction and with a particular velocity. This type of motion is called translational motion. Second, the molecule may rotate about some internal axis. Finally, the molecule may vibrate.

The purpose of this article is to give an introduction to molecular vibration. An understanding of molecular vibration is important in the fields of superconductor research and infrared spectroscopy.

Wavenumber

The wavenumber is the reciprocal of the wavelength ($1/\lambda$) of light necessary to excite the vibration mode.

Note that the propagation speed c and the frequency f are related to the wavelength λ by

$$c = f \lambda \quad (2.1)$$

Carbon Monoxide CO

Carbon monoxide has a single mode, called a symmetric stretch mode. The wavenumber is 2143 cm^{-1} . The corresponding natural frequency is 64.29 tetrahertz. The two nuclei alternately stretch outward and then compress inward at this frequency, as shown in Figure 2-1. The molecule can be considered as a mechanical system with a spring and two masses. Each nucleus is a mass. The chemical bond between the nuclei is the spring.

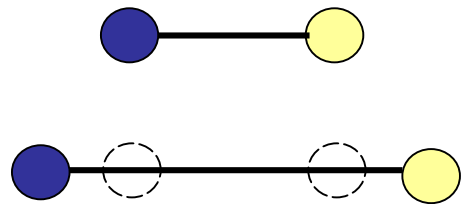


Figure 2-1. Carbon Monoxide Vibration Mode

The top image is the undeformed molecule. The bottom shows the fully stretched molecule.

Diatomic Frequency

Diatomic molecules such as carbon monoxide have a natural frequency f_n given by

$$f_n = \left[\frac{1}{2\pi} \right] \sqrt{\frac{k}{m_r}} \quad (2.2)$$

where

k is the bond force constant, or stiffness

m_r is the reduced mass

The reduced mass is

$$m_r = \frac{m_1 m_2}{m_1 + m_2} \quad (2.3)$$

where m_1 and m_2 are the respective nuclei mass values.

Carbon monoxide has the properties given in Table 2-1, as calculated by equations (2.2) and (2.3).

Table 2-1. Carbon Monoxide Properties			
$f_n =$	$64.29 (10^{+12})$	Hz	CO
$m_1 =$	$1.99 (10^{-26})$	kg	C
$m_2 =$	$2.66 (10^{-26})$	kg	O
$m_r =$	$1.14 (10^{-26})$	kg	CO
$K =$	8158	N/m	CO

Carbon Dioxide CO₂

Carbon dioxide is a linear, triatomic molecule. An undeformed carbon dioxide molecule is shown in Figure 2-2. The vibration modes are given in Table 2-2, as taken from Reference 2-1.

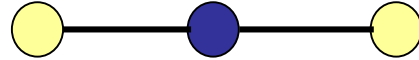


Figure 2-2. Carbon Dioxide Molecule

Water Molecule H₂O

Water is a nonlinear, triatomic molecule. An undeformed water molecule is shown in Figure 2-3. The vibration modes are given in Table 2-3, as taken from Reference 2-1.

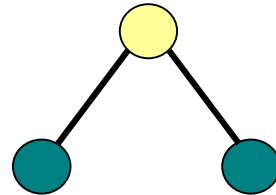
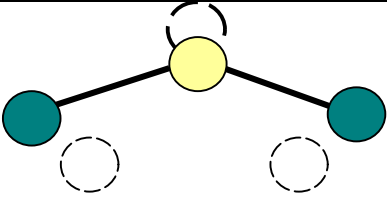
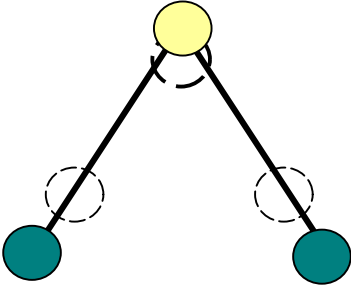
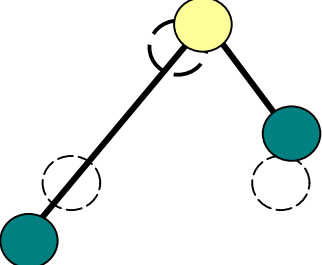


Figure 2-3. Water Molecule

Table 2-2. Carbon Dioxide Vibration Modes	
	Bending Mode $\nu_1 = 667 \text{ cm}^{-1}$
	Bending Mode $\nu_2 = 667 \text{ cm}^{-1}$
	Symmetric Stretching Mode $\nu_3 = 1340 \text{ cm}^{-1}$
	Antisymmetric Stretching Mode $\nu_4 = 2349 \text{ cm}^{-1}$

Table 2-3. Water Molecule Vibration Modes

	<p>Bending Mode</p> <p>$\nu_1 = 1595 \text{ cm}^{-1}$</p>
	<p>Symmetric O-H Stretching Mode</p> <p>$\nu_2 = 3652 \text{ cm}^{-1}$</p>
	<p>Antisymmetric O-H Stretching Mode</p> <p>$\nu_3 = 3756 \text{ cm}^{-1}$</p>

Dipole Moments

A molecule may absorb infrared energy at its vibration frequencies depending on the corresponding mode shape characteristics. Specifically, this absorption can occur if the mode shape has a change in the electric dipole moment.

The electric dipole moment for a pair of opposite charges of magnitude q is defined as the magnitude of the charge times the distance between them and the defined direction is toward the positive charge.

The vibration modes are thus classified according to whether they are IR active or inactive depending on whether a change in the dipole moment occurs.

A simple method to determine whether this change occurs for a triatomic molecule is to take the resultant vector sum of the two charge vectors. If the resultant vector remains constant throughout the mode shape oscillation, then the mode is IR inactive. If the resultant vector changes, then the mode is IR active.

Water and Carbon Dioxide IR Activity

Each of the three modes of a water molecule is IR active because each involves a net oscillation of the dipole moment.

The carbon dioxide stretching mode is IR inactive because the two CO bonds always cancel. The other three modes are IR active. The two orthogonal bending modes occur at the same frequency, however. Thus, there are only two IR absorption bands for carbon dioxide, compared with three bands for water.

Quantum Harmonic Oscillator

A vibrating molecule is considered a quantum harmonic oscillator. The energy E of the quantum harmonic oscillator must be at least

$$E = \frac{(\Delta p)^2}{2m} + \frac{1}{2} m \omega^2 (\Delta x)^2 \quad (2.4)$$

where

Δp = momentum uncertainty

Δx = position uncertainty between nuclei

Equation (2.4) is form of the Hamiltonian for a simple harmonic oscillator.

Furthermore, the minimum energy E_0 at the "ground state" can be expressed as

$$E_0 = \frac{1}{2} \hbar \omega \quad (2.5)$$

where

\hbar is Planck's constant

The energy of the ground vibrational state is often referred to a "zero point vibration."

Equation (2.5) is a very significant physical result. It shows that the energy of a system described by a harmonic oscillator potential cannot have zero energy.

Physical systems such as atoms in a solid lattice or in polyatomic molecules in a gas cannot have zero energy even at absolute zero temperature.

This implies that molecules are not completely at rest, even at absolute zero temperature.

The zero point energy is sufficient, for

example, to prevent liquid helium-4 from freezing at atmospheric pressure, no matter how low the temperature.

Potential Energy Levels

A vibrating molecule has discrete potential energy levels given by

$$E_n = \left(n + \frac{1}{2} \right) \hbar \omega, \quad n=0, 1, 2, 3 \dots \quad (2.6)$$

where ω is the natural frequency.

Equation (2.6) gives the “energy eigenvalues.”

Note that for a diatomic molecule,

$$\omega = \sqrt{\frac{k}{m_r}} \quad (2.7)$$

Furthermore, equation (2.5) is a special case of equation (2.6).

The energy levels for a diatomic atomic are represented in Figure 2-4, as taken from Reference 2-2.

Phonons

Electromagnetic energy behaves as a wave in certain instances and as a particle in others. An electromagnetic particle is called a photon.

There is an analogy for quantum harmonic vibration. Vibrational energy in certain phenomena behaves as discrete bundles of energy. A single bundle is called a phonon.

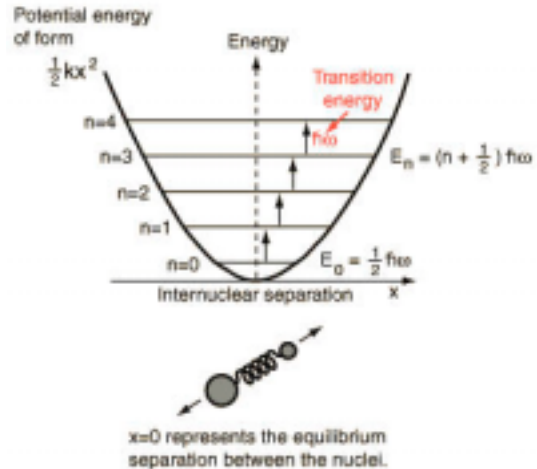


Figure 2-4. Potential Energy Levels

Furthermore, a phonon is considered as an energy step of $\hbar \omega$ as shown in Figure 2-4.

The importance of phonons arises in a number of fields. For example, interactions between phonons and electrons are thought to be responsible for such phenomena as superconductivity.

Another area is the ultrasonic testing of materials for integrity evaluation. University of Illinois professor Richard Weaver and associate Oleg Lobkis have measured the phonon energy in a sample block of aluminum. They obtained the same noise signals from the naturally occurring, or passive, energy as they did when they excited the block with ultrasonic pulses from a transducer.

In principle, the passive technique could work on nearly any object, but would be most helpful in applications where conventional sound sources are scarce. The technique could also be used to non-invasively probe micron-sized features and material properties in microchips.

Excitation Source

Molecular vibration modes are usually excited by thermal energy.

An increase in a materials temperature is accompanied by an increase in the number of phonons.

References

2-1. <http://www-biol.paisley.ac.uk/chemistry/home/staff/bstewart/teaching/inorg3/VIBSPEC/VIBSPEC3.HTM>

2-2. <http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/hosc.html#c1>