Technical Training

Scientific Measurements Technician

INTRODUCTION TO DETECTION SYSTEMS

18 October 1984

3400 TECHNICAL TRAINING WING
3454 School Squadron
Lowry Air Force Base, Colorado

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DETECTION SYSTEMS

OBJECTIVES

- From five statements select only those statements describing significant events in the history and development of detection systems utilized by AFTAC.
- Complete five statements describing the operational concepts of detection systems employed by AFTAC.
- Match four detection systems employed by AFTAC to a statement depicting how it contributes to mission accomplishment.

INTRODUCTION

This unit of instruction is designed to familiarize you with the detection systems employed by AFTAC. The materials presented are an overview of the history and development of monitoring systems, the operational concept of current systems, and the contributions each make to mission accomplishment.

It is hoped that this unit will instill a sense of mission importance and spur you to study the impact of nuclear weapons development on the policies of all nations.

The history and development of the detection systems employed by AFTAC are closely linked to the proliferation of nuclear power. The U.S. was the first to detonate a nuclear device and the first to establish a network of monitoring systems. Ironically, as we will see, many of the same individuals who developed the atomic bomb are also the staunchest supporters of a nuclear freeze.

INFORMATION

HISTORY AND DEVELOPMENT

The Nuclear Club.

On the morning of July 16, 1945, in the desert near Alamagordo, N.M. an event occurred that will dominate history forever. The United States successfully completed the largest laboratory experiment ever attempted; the detonation of the first nuclear device. Code-named Trinity, the test culminated the most intense research and development program ever undertaken.

During the years 1943 through 1945 more than 10,000 people were gathered at a converted boys school near the desert community of Santa Fe, New Mexico. The Los Alamos Laboratory, under the direction of Dr. J. Robert Oppenheimer, was established there and tasked to develop a weapon of awesome destructive power. Physicists from around the world worked night and day on what was termed the "Manhattan Project".

Despite common perception, the thought of such a weapon was by no means a new idea. As early as August 1939, Dr. Albert Einstein, in a letter to President Roosevelt stated, in part "it may become possible to set up a nuclear chain reaction in a large mass of uranium, by which vast amounts of power and large quantities of new radium-like elements would be generated....... This new phenomenon would also lead to the construction of bombs, and it is conceivable, though less certain, that extremely powerful bombs of a new type may thus be constructed". Dr. Einstein's letter caught the respectful interest of Mr. Roosevelt and truly launched the United States effort to build an atomic bomb.

The power of such a weapon was demonstrated to the world on August 6, 1945 at Hiroshima, Japan. On that day more than 70,000 people lost their lives and 62,000 of the city's 90,000 buildings were reduced to rubble. A second bomb was dropped at Nagasaki on the 9th of August and the war in the Pacific ended on the 15th.

The end of the war left the American people secure with the idea that no other country could produce a nuclear weapon. Oppenheimer himself said in a conversation with Dr. Edward Teller that "We have done a wonderful job here (Los Alamos), and it will be many years before anyone can improve on our work in any way."

Soon, stark realizations began to chip away this false security. Politicians began to recognize that many of the physicists involved in the development of the atomic bomb were European born. Moreover Russia was not willing to accept a plan that the U.S. proposed to the United Nations. This plan would have placed control of nuclear development in the hands of an international committee and, in effect, made our knowledge available to anyone. Finally, it was revealed that a group of Japanese physicists had tried unsuccessfully to produce an atomic weapon toward the end of the war. Reports to the Japanese government in early 1945 stated that major obstacles had been overcome and more critical experiments were to begin.

Awareness that other countries could, and eventually would, develop nuclear capability led to the subsequent endorsement of an Atomic Energy Detection System (AEDS) concept. In September 1947, Gen. Dwight D. Eisenhower directed the Army Air Forces "to detect atomic explosions anywhere in the world." This task remained with the Air Force when it became a separate service (18 September 1947) and was vested in the Air Force Technical Applications Center (AFTAC). Prior to being AFTAC, a special task force within the Air Force was assigned to "operate and maintain the AEDS".

The value of the AEDS was proven in September 1949 when an AFTAC sensor aboard a B29 detected debris from the first Soviet atomic test.

This detection is especially noteworthy since most experts had predicted that the first Soviet test could not occur before 1951. In 1949, Western scientists and politicians did not believe that the Soviet Union, or any other country, was scientifically sophisticated enough to produce atomic weapons. This was a mistake.

Ardently supported atomic physics research had been conducted in the USSR for many years. In June of 1944 the Soviets knew the purpose of Los Alamos. By June of 45 they were aware that the first test was scheduled for the following month, and by September had a detailed description of the device dropped at Nagasaki. Since its establishment, a vast network of Soviet spies had been collecting every available piece of information about the operation at Los Alamos and reporting it to Moscow. Of these, Klaus Fuchs was undoubtedly the most important to their cause.

Fuchs had fled Europe and Hitler's Nazis in 1933. Eventually interned in Canada, he was screened and released in 1942 to help with Britain's atomic research. He became a full fledged member of the British team and travelled to Los Alamos in 1944. He worked freely at the laboratory and was allowed access to the facilities' most sensitive secrets.

A friendly, quiet man, Fuchs often talked at great length with many of the physicists involved in the project. Throughout his tenure, he relayed all he knew to a soviet spy, Harry Gold. It is ridiculous to believe that the Soviets could not have developed atomic weapons without the information provided by Fuchs, but it is more ridiculous to think that his reports did not make their task easier.

On August 7, 1945, the day after Hiroshima, Soviet research intensified. Convinced that atomic weapons could be constructed, Soviet Premier Joseph Stalin designated his chief of security, Lavrenti Beria, supervisor of atomic research. Beria headed a Russian version of the "Manhattan Project" that resulted in the surface detonation of a device in the Ust-urt desert on August 29, 1949.

This first Soviet test was followed by a series of unannounced explosions that, by the summer of 1953, matched the yield of on-going American tests.

Since the 40's four other countries have demonstrated a nuclear power, reinforcing the need for an AEDS.

In 1952 Great Britain tested an atomic bomb in a small group of islands off the west coast of Australia. They continued small atomic tests in Australia throughout the 50's, and in 1957 tested their first hydrogen thermonuclear device at Christmas Island. the British continue to test underground devices at the Nevada Test Site in cooperation with the United States.

During the 50's, France, under the leadership of General Charles de Gaulle, began to strenghten its government and military. By the mid 70's the Army, Navy, and Air Force were to be nuclear armed.

Beginning in 1960, and continuing through 1967 the French conducted surface and underground tests of atomic devices in Algeria, Africa. However, the search for a suitable site for fusion bomb testing led to Mururoa Atoll, a French possession in the South Pacific, where nuclear testing began in 1966 and continues today.

On October 16, 1964 the first Chinese nuclear fission device was detonated in the atmosphere near Lop Nor, Sinkiang province. The Chinese nuclear capability, although disputed, was heavily supported by Russion technology. Technical assistance from the Soviets began in 1957 and continued until 1960 when, due to ideological differences, the Soviets withdrew all of their advisory forces. The Chinese resolve to develop a nuclear capability was thus strengthened. Chairman Mao Tse-tung summoned his leading physicists and directed that China must have an atomic weapon by January 1, 1965. Obviously, the physicists beat their assigned deadline.

Finally, on May 18, 1974, India became the last member of the nuclear club. Purportedly constructed with only Indian resources the device provided a yield of 10-15 kilotons. Immediately following the test the chairman of the Indian Atomic Energy Commission announced that nuclear devices would only be used for peaceful purposes and no subsequent tests have been recorded.

Unfortunately, the members of the nuclear club are often at odds. The fears of nuclear proliferation and war that led to the creation of an AEDS, and subsequently AFTAC, have sustained both organizations and continues to upgrade their importance. Over the years, many attempts to dispel these fears have resulted in several treaties that present an interesting chronology.

Treaties

In March 1946 the first workable plan for control of atomic energy was made public. Originally known as the Acheson-Lilienthal Report, it called for the formation of an international agency to monitor atomic energy. The agency would control all of the world's raw materials, operate the world's atomic reactors, and license the raw materials necessary for research. This report was presented to the United Nations as the Baruch Plan and, as mentioned earlier, met stiff opposition from the Soviets. The U.S. was trying to deal with a commodity (knowledge of atomic energy) that the USSR already possessed. Additionally, the plan required on-site inspection to insure compliance. This requirement caused dissent throughout the 1950s. Neither side of the debate (US and USSR) would agree on the number of inspections to allow. This single issue created an impasse that lasted until the early 1960's. The dawn of the 1960s brought about a rash of treaties, some of which are listed for reference.

ANTARCTIC TREATY. 1961. The Antarctic Treaty bars military activity, including nuclear tests in Antarctica and is significant in that it was the first multilateral disarmament treaty signed after WWII.

The treaty prohibits any military activities in Antarctica, such as establishing bases, conducting maneuvers, or testing any kind of weapon. It also prohibits exploding nuclear charges and the dumping of nuclear wastes south of 60° S. latitude.

To verify compliance with the treaty the 17 contracting parties are allowed to designate observers to conduct on-site inspections at any time.

LIMITED TEST BAN TREATY (LTBT). 1963. This treaty prohibits testing nuclear devices in the atmosphere, in space, and underwater. Notably, it does not prohibit underground explosions but does ban tests that would cause radioactive debris (fallout) outside the territory where the explosion is conducted. The treaty has, however, lowered the level of high yield tests, made it impossible to test a weapon in its intended environment, and slowed radioactive contamination of the atmosphere.

Unfortunately, the treaty does not specify how compliance by the 106 contracting parties is verified. However, there have to date been only 14 reported violations, 8 by the Soviets and 6 by the US.

Of the nuclear powers, China, France, and India have not signed the treaty along with many near-nuclear states.

OUTER SPACE TREATY. 1967. The Outer Space Treaty prohibits placing nuclear, as well as other kinds of weapons of mass destruction, in earth orbit and limits the use of the moon and other celestial bodies to peaceful purposes. Additionally, the treaty prohibits establishment of military bases, testing of any kind of weapon, and military maneuvers on celestial bodies.

The 71 signatories of this treaty have since the early 60's voluntarily registered all objects launched into space. This act is in accordance with the principle of the treaty stating that states bear international responsibility for national activities in outer space.

LATIN AMERICAN NUCLEAR FREE-ZONE TREATY. 1968. This treaty bans nuclear weapons from Latin America. The treaty aims at making Latin America a nuclear-free zone and prohibits "testing, use, manufacture, production or acquisition by any means as well as receipt, storage, deployment, and any form of possession of nuclear weapons by countries in Latin America". One article defines a nuclear weapon as "any device which is capable of releasing nuclear energy in an uncontrolled manner and which has a group of characteristics that are appropriate for use for warlike purposes".

There is some dissent over the right to conduct peaceful nuclear explosions, however, overall the treaty is honored. An organization (Agency for Prohibition of Nuclear Weapons in Latin America) has been established to ensure compliance with the treaty.

NON-PROLIFERATION TREATY (NPT). 1970. This treaty bars supplying nuclear weapons to non-nuclear states. Basically, the treaty stops the spread of nuclear weapons and aims at limiting the number of nuclear countries to those having nuclear weapons in 1967. Nuclear weapon states, defined by the treaty as those states having carried out a nuclear explosion prior to 1967, are prevented from assisting non-nuclear states in acquiring nuclear devices. Additionally, a non-nuclear weapon state party to the treaty is prohibited from manufacturing nuclear devices. They may, however, make the necessary preparations for the manufacture of nuclear weapons without violating the treaty.

All parties to the treaty have a right to use nuclear energy for peaceful purposes.

Again, among the nuclear powers, China, France, and India have not signed the treaty along with many near-nuclear states.

SEA-BED ARMS CONTROL TREATY. 1972. This treaty bans placing any nuclear weapons or any other weapon of mass destruction; as well as structures; launching installations; or facilities for storing, testing or using such weapons on the seabed, ocean floor or in the subsoil thereof beyond the outer limit of the 12 mile zone established by the Convention on the Territorial Sea and the Contiguous Zone of 1958.

The treaty is adhered to by all of the nuclear powers except China and France and has a total of 55 contracting parties.

Each party to the treaty has the right to ensure compliance, through observation, of any other signatory. If a violation is suspected, consultation between the parties is held. If the situation persists, other parties must be notified, and cooperation for further verification, including inspection, may be agreed upon. If doubt still remains, the matter is referred to the UN Security Council.

THRESHOLD TEST BAN TREATY (TTBT). 1974. The TTBT prohibits underground tests with yields exceeding 150 KT. A bilateral agreement between the US and USSR, the treaty limits yields to less than 150 KT and to defined test sites.

To ensure compliance with the treaty each party agrees to use "national technical means" of verification in a manner consistent with international law. They also agree not to interfere with each others' methods of verification. A protocol of the treaty also specifies "reciprocal exchange" of data to facilitate verification to include data on the location and geological characteristics of the test areas. Moreover, the yields of two explosions in each geophysically distinct test area must be provided for calibration purposes.

PEACEFUL NUCLEAR EXPLOSIONS TREATY (PNE). 1976. This treaty limits explosions for peaceful purposes to prevent the use of such explosions to develop new weapons. The PNE Treaty is a bilateral agreement that compliments the TTBT. The provisions of the treaty are extensive and place many restrictions on any explosion carried out at any place other than a test site. Simply put, any explosion having a yield exceeding 150 KT and any group explosion with an aggregate yield exceeding 1500 KT is banned. Detailed restrictions described in the protocol are put on the emplacement of both individual and group explosions. There is, for example, a minimum depth requirement on any explosion.

The treaty requires extensive bilateral procedures for verification. The aim of the verification measures is essentially to ensure that no individual explosion has a yield exceeding 150 KT. The treaty is notable in that the methods of verification required are tied to yield. The greater the yield, the more extensive the compliance verification procedures. Unlike any other treaty, the parties agree to on-site inspection of explosions exceeding 150 KT.

COMPREHENSIVE TEST BAN TREATY (CTBT). UNSIGNED. Talks on a treaty to ban all nuclear explosions have been suspended since 1980. Failure of the concerned parties to agree on methods of verification, again, is the major cause of the impasse. However, the question of a CTBT is still under consideration by the UN Committee on Disarmament. Characteristically, there is little hope of an early agreement.

The material presented thus far forms the basis, or need, for an AEDS, but what about the development of equipment utilized with the AEDS. We know that equipment development is necessarily linked with advances in nuclear weapons technology and that disagreement on methods of verification have permeated every attempt at reaching agreement on a CTBT. As stated earlier, concerns about nuclear proliferation have been expressed since the early months after the end of WWII. These concerns culminated in the formation of the AEDS and ultimately AFTAC. So much for the birth of AFTAC, but how do we accomplish our assigned mission.

DETECTION CONCEPTS

Over the years, AFTAC's operational concepts have been continually updated and refined to meet the requirements imposed by technological advancement. In order to remain responsive to its mission tasking, AFTAC has needed to improve the reliability and capabilities of its detection systems.

Before discussing the operational concept of each system we must understand the phenomena that occur when a nuclear device is exploded.

The Nature of Matter

The physical universe is composed of what is called matter, yet it is difficult to precisely define matter. It is customary to refer to states of matter as solid, liquid, or gas and say that matter has certain physical properties, such as color and/or hardness. All of this simply tells us about matter, not what matter is.

Centuries ago, Greek philosophers argued over whether the smallest pieces anything could be divided into were just miniatures of the original or that at some point particles would be found that were combined in different ways to form a substance.

It is now known that the second argument is correct. These independent particles are called atoms. Therefore, to understand matter, we must first learn about the atom.

ATOMS. All matter appears essentially electrical in nature. After rubbing together pieces of amber and fur it is shown that both materials are capable of picking up light pieces of other material. However, those attracted by the amber are repelled by the fur and vice versa. From this, scientists determined that there are two types of electrical charge; positive and negative. Additionally, like charges (positive or negative) repel each other and unlike charges attract each other.

When amber and fur are rubbed together particles pass from the fur to the amber, and the amber becomes negatively charged. Therefore, the particles that bring about this condition must be negatively charged.

The negatively charged particles are called electrons and are fundamental particles of atoms. However, atoms cannot consist of electrons alone. If this were true, all atoms would be negatively charged and repel each other.

The positive particles of an atom are called protons. Protons have greater mass than electrons.

The final particle of an atom is the neutron. Neutrons are approximately equal in mass to a proton, but unlike the proton and electron, they are not electrically charged. Finally, the electron, proton and neutron are the fundamental particles that combine to form atoms and ultimately matter.

ATOMIC STRUCTURE. Repeated tests have shown that atoms contain a nucleus of protons and neutrons about which the electrons orbit. They also reveal that a normal atom has as many electrons as it has protons. The neutrons contribute to the mass of the atom but do not effect its charge. Spinning rapidly about the nucleus, much like a shield, the electrons give size to the atom. Figure 1 depicts atoms sharing electrons with each other, a normal occurrence in nature.

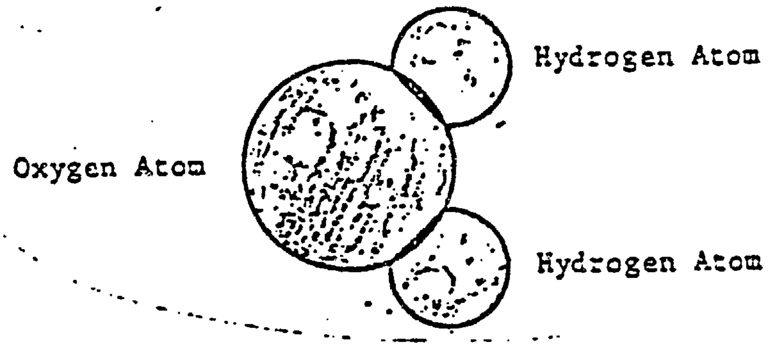


FIGURE 1
MOLECULE OF WATER

ELEMENTS. An atom is the smallest unit of an element. Each element is a special combination of protons, neutrons and electrons. The distinguishing feature of each element is the number of protons contained in its nucleus. Figure 2 is a table listing the known elements.

ISOTOPES. Every element has forms that, though essentially identical in chemical and physical properties, have different masses. Such forms of an element are called isotopes. Each isotope has the same number of protons in its nucleus as the basic element but a different number of neutrons. Hence, isotopes show differences in mass when compared to the basic element. For example, hydrogen with one proton and no neutrons in its nucleus has a mass number of 1. When a neutron is present, however, the atom is an isotope of hydrogen, with a mass number of 2, called deuterium.

Information about atomic structure is expressed symbolically by a subscript number prefixed to the element's symbol to indicate the atomic number and by a superscript indicating the mass number. Thus hydrogen is represented by ${}^{1}_{1}H$ and the isotope deuterium ${}^{2}_{1}H$.

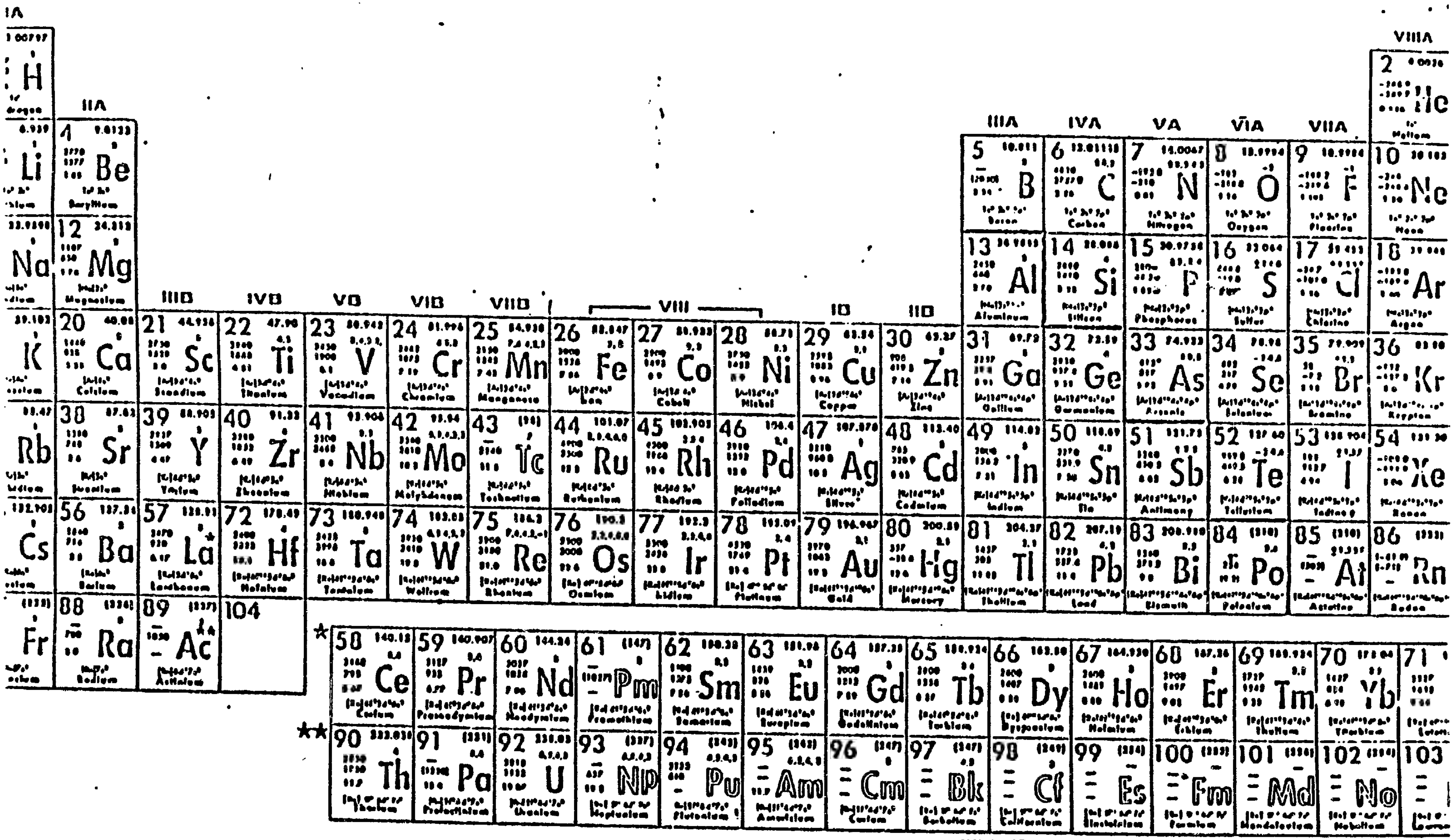


Figure 2. ELEMENT CHART

COMPOUNDS. Compounds are combinations of atoms of different elements. Those formed by life processes are organic compounds. All others are inorganic compounds.

The number of electrons in the outer shell of an atom determines the ease with which the atom can join with other atoms to form compounds. Therefore, compounds are formed by different atoms gaining or losing electrons. When two or more elements combine to form a compound the result is called a molecule. A molecule is the smallest unit of a compound.

SUMMARY ON MATTER. Matter is the substance of the physical universe and is comprised of a combination of atoms. An atom is the smallest unit of an element and is seldom found alone in nature. They are found in combination with each other and other atoms. Atoms of different elements combine by exchanging or sharing electrons to form compounds. The smallest unit of a compound is a molecule.

Nuclear Reactions

There is a fundamental difference between a nuclear and chemical reaction inasmuch as a nuclear reaction involves the nuclei, but a chemical reaction involves only the electrons of the atoms. This means that in a chemical process the elements are the same after the reaction as they were before the reaction, although they may appear in new combinations, whereas in a nuclear reaction new elements are created.

The mass of a nucleus is less than the sum of the masses of the nucleons (protons and neutrons) constituting the nucleus, and the mass difference represents the binding energy of the nucleus. According to Einstein's formula, the mass difference, m, corresponds to an equivalent amount of energy, $E = mc^2$, where c is the velocity of light. The mass difference, and thus the binding energy, is different for different nuclei.

There are basically two different ways to release energy by a nuclear reaction, either to split an element with many nucleons say, 200, into elements having less nucleons but higher bonding energy per nucleon, or to combine elements with few, say 2-6 nucleons, into one or more elements having more nucleons and thus higher bonding energy per nucleon. The process of splitting "heavy" elements into "light" ones is called fission, and the process of combining light elements to form heavy ones is called fusion.

FISSION. A fission explosion is often called an atomic explosion, or A-Bomb, like those dropped at Hiroshima and Nagasaki. The elements used as the explosive material in nuclear fission devices are uranium (U) and plutonium (Pu). Two isotopes of uranium, ${}^{235}_{92}U$ and ${}^{233}_{92}U$, with 235 and 233 nucleons, respectively, and the plutonium isotope $^{239}_{94}Pu$, with 239 nucleons, are used. The nuclear reaction of the $^{235}_{92}U$ isotope is typically written:

neutron + $^{235}_{92}U$ 2 fission fragments + about 3 neutrons +

- radiation + energy (and similarly $^{233}_{92}U$ and $^{239}_{94}Pu$).

This means that a uranium or plutonium nucleus captures a neutron, splits up into two fission fragments of different kinds, and produces an average of three neutrons as well as radiation and energy. A most important point is that the fission process generates more neutrons than it consumes, and due to this effect it is possible to create and sustain a chain reaction. A minimal amount of fissile material is needed to sustain the reaction, so that the produced neutrons do not escape from the process. This so called critical mass depends on the composition and geometry of the fissile material, presence of impurities, and on the presence or absence of a neutron reflector, called a tamper, surrounding the fissile material and minimizing the neutron loss.

FUSION. In the fusion process the energy is derived from forcing together nuclei of light elements. Two isotopes of hydrogen, deuterium, $^{2}_{1}D$, and tritium, $^{3}_{1}T$, are most commonly used in the fusion process. As isotopes of hydrogen, with the chemical symbol H, are used in the fusion process, these devices are often called H Bombs. An example of the fusion reaction is: $^{2}_{1}D$ + $^{3}_{1}T$ ^{4}He + neutron + energy, where one deuterium and one tritium nucleus are combined to produce one helium (He) nucleus, one neutron, and a determined amount of energy. To start the fusion process the nuclei must be very close together, which means that they must have energies high enough to overcome the repelling force of equally charged nuclei. Such energies are achieved by increasing the temperature to tens of millions of degrees, where the material consists of free nuclei and electrons, plasma, and the nuclei have enough thermal energy to start a fusion reaction. A reaction based on the thermal energy of the nuclei is often called a thermonuclear reaction. To sustain a thermonuclear reaction, the energy produced must be larger than that radiated from the process; otherwise the temperature decreases and the reaction stops.

Bomb designs.

A fission device requires two components. The first is a subcritical mass arranged in such a way that it can almost simultaneously be made supercritical. The second is a strong neutron source to initiate the reaction. There are two ways to construct such a device.

GUN METHOD. In the gun method two or more pieces of fissile material, each of subcritical size, are brought together by conventional explosives to form a supercritical system, where upon the chain reaction is initiated by a neutron source. Refer to Figure 3.

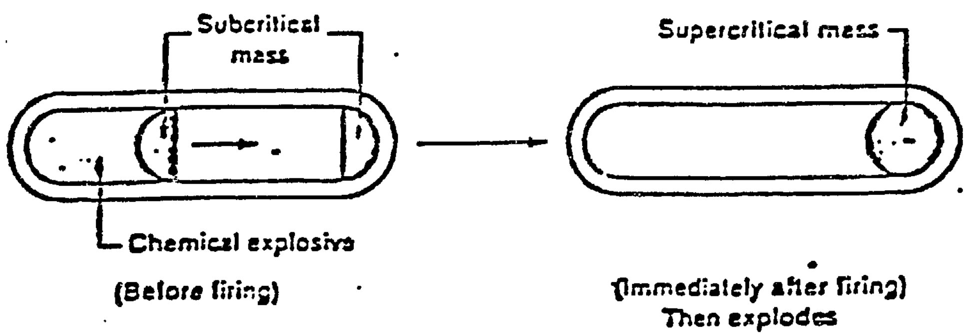


Figure 3
GUN METHOD

IMPLOSION METHOD. With the implosion method, the nuclear material is in the form of a subcritical shell, which, at the explosion moment, is compressed by conventional high explosives to a compact supercritical mass and the chain reaction is initiated. Figure 4 depicts this construction method.

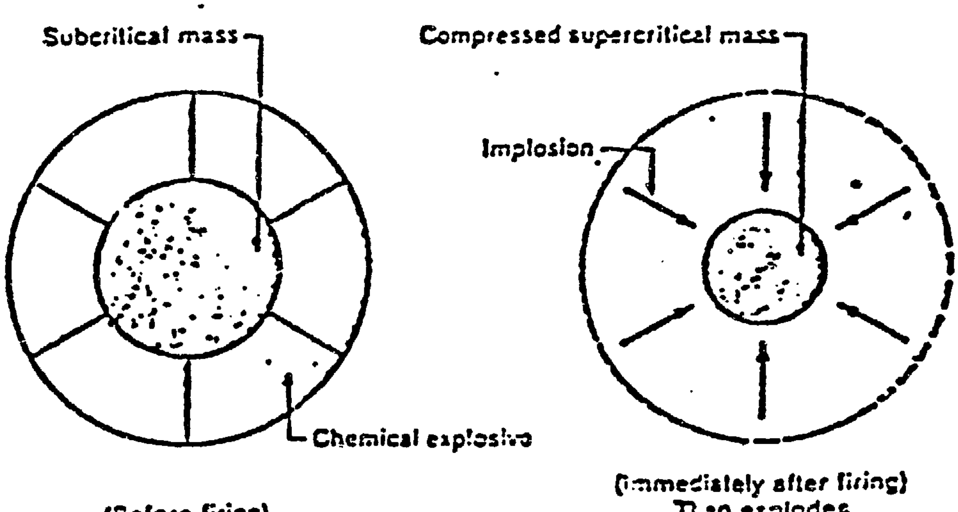


Figure 4
IMPLOSION METHOD

The principle construction of nuclear fusion devices is not generally known in as much detail as that of fission devices. Presently, it appears that only a fission explosion is capable of producing the temperatures necessary for a thermonuclear reaction to start, and trigger fusion.

A fusion bomb with a fission part contributing only a few percent of the total yield seems possible. The possibility of initiating a fusion explosion by means other than a fission reaction, for example high energy laser radiation, and thus to obtain a pure fusion explosion have been discussed, but no substantial progress has been reported.

Nuclear Explosion Phenomena.

For a chemical (TNT) explosion the detonation velocity is about 6000 m/s which means that a 1 Kt sphere with a radius of 5.5 m detonates within a millisecond. The produced explosion gasses have an initial pressure of about 200,000 atmospheres and a maximum temperature of 3000°K. Almost all of the energy released in a chemical explosion is converted to shock-wave energy. In a nuclear explosion the energy is produced within a very short time, less than a microsecond. Immediately after the explosion the energy is deposited within a small volume of hot and compressed gas. In a fission explosion the initial gas temperature amounts to tens of millions of degrees Kelvin and the pressure exceeds a million atmospheres. The hot gas emits electromagnetic radiation in the form of X-rays. This radiation is absorbed very rapidly and heats the surrounding media, so at this stage the energy propagates outward as thermal radiation. The heated material also compresses the surrounding media, and a very hot shock wave results. For an explosion in the atmosphere, 50% of the explosion energy is converted to blast and shock wave energy, 35% to thermal radiation, and the remaining 15% is initial and residual radiation.

In an underground nuclear explosion, the thermal radiation is absorbed by the surrounding dense material. Therefore, the sphere of action is much smaller than that of an atmospheric one. The close-in explosion phenomena for a fully contained underground explosion are illustrated in Figure 5. The intense shock wave of high temperature melts or vaporizes the material in the immediate vicinity of the explosion and forms an approximately spherical cavity. Outside the cavity, inelastic deformation and cracking of the rock occur up to a certain distance beyond which the material acts elastically. Analysis indicates that 90 to 95% of the released explosion energy is deposited as thermal energy in the vicinity of the explosion.

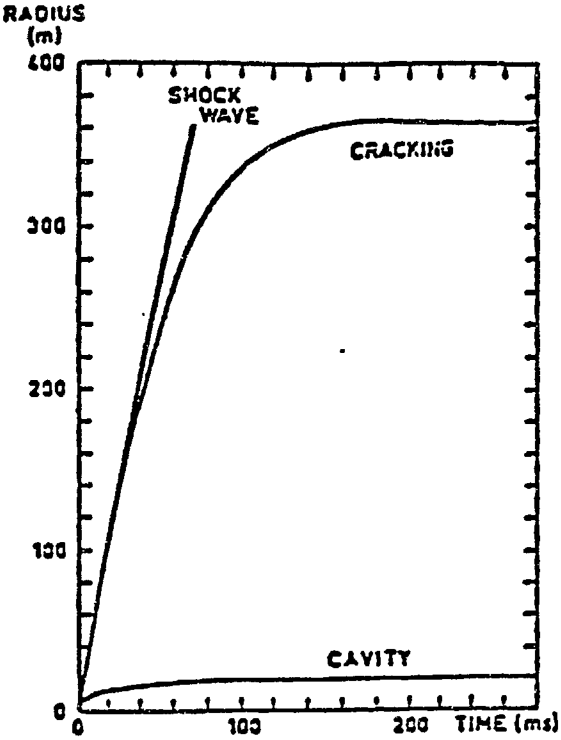


Figure 5
CLOSE-IN EXPLOSION PHENOMENA

In studies of seismic waves generated by underground nuclear explosions, the detailed behavior of the inelastic zone are not considered. The seismic source of an underground explosion is usually considered an elastic sphere having a radius equal to the distance from the explosion point to where the material begins to act elastic.

Finally, for an explosion underwater, up to 40% of the total energy produced is in the form of a shock wave.

OPERATIONAL CONCEPTS

In the past AFTAC has utilized many systems to detect the phenomena resulting from the detonation of a nuclear device. Several of these were the result of research and development projects, and due to technological advances have been modernized, deleted, or replaced.

In order to operate and maintain the AEDS, AFTAC manages locations in more than thirty five countries. The headquarters is located at Patrick AFB, Florida, with the Technical Operations Division at McClellen AFB, California and operating areas at Wheeler AFB, Hawaii and Lindsey AS, Germany. There are nineteen detachments (Dets), four operating locations(OLs) and more than fifty equipment locations (ELs) around the globe.

The operating areas in Hawaii and Germany provide administrative and logistic support to subordinate units within their geographical areas of responsibility. The TOD located at McClellan supports three separate activities, the Central Laboratory, the Logistics Depot, and the Airborne System.

McClellan Central Laboratory

The Central Laboratory (MCL) is a scientific facility utilizing modern analytical equipment in support of the AEDS mission. Approximately 100 different techniques are employed to accomplish this task. Aside from managerial and support offices, the MCL is divided into three separate laboratories.

APPLIED PHYSICS LABORATORY. This section of the MCL is responsible for sample preparation, optical characterization, instrumental analysis, identification of samples, and precision isotopic measurements of samples. Additionally, it assists in the evaluation of data derived from other analysis techniques and conducts research and development to improve the quality of analysis.

RADIATION ANALYSIS LABORATORY. This section is responsible for managing the flow of samples through chemical processing techniques involving dissolution, separation, purification, and instrumental analysis. Measurement of chemically separated radioactive samples using alpha, beta, and gamma detection systems is also accomplished here. Moreover, this section performs measurement of radioactive samples in the form of filter papers, solutions, gas samples, and other "as received" samples.

GAS ANALYSIS LABORATORY. This laboratory performs separation, purification and measurement of all radioactive gasses of interest to AFTAC.

LOGISTICS DEPOT. Because the unique systems and instrumentation are only applicable to the AEDS mission, the depot distributes items managed by AFTAC. Additionally, the depot prepositions assets for AEDS systems, provides parts support for depot level maintenance, and provides normal base level support.

The dets, ELs, and OLs facilitate mission accomplishment by providing operational environments for placement and implementation of equipment utilized by AFTAC. The mission requirement to detect debris in all mediums results in the employment of many diverse techniques.

Airborne Systems

AFTAC utilizes airborne particulate and gas sampling devices to confirm, and subsequently track, clouds of nuclear debris. Filtering devices and pressurized spheres mounted aboard modified aircraft collect samples that are forwarded to MCL for analysis and classification.

Ground Based Systems

There are three ground based systems that provide samples to the MCL for analysis and classification.

GROUND FILTER UNIT (GFU). The GFU is an electrically powered, ground based, air filtering unit. It is designed for continuous operation, employing an electric motor coupled to a blower assembly. Free air is drawn into a transition cone, flows through a filter element (paper), and is then exhausted to the atmosphere. The filter paper containing airborne particles collected from the atmosphere, is then removed and forwarded to the MCL for analysis and classification.

GROUND MOISTURE UNIT (GMU). The GMU is a ground based, whole air sampling device. Two glass traps are employed in the unit. The first contains a molecular sieve that removes water vapor from free air. The second trap contains a molecular sieve coated with palladium. The palladium acts as a catalyst to oxidize gaseous hydrogen and form water vapor that is absorbed. The unit is designed to operate continuously. The traps are changed daily and forwarded to MCL for analysis and classification.

B20-5. The B20-5 is an automated cryogenic distillation device that employs very low temperatures to isolate rare elements (gasses) contained in the atmosphere. The unit is designed to operate continuously over any preset sample run of 24 hours (or multiples thereof) for periods of up to seven days. Samples are collected in 800 cc metal containers that are forwarded to the MCL for analysis and classification.

Seismic System

The seismic system consists of a global network of manned stations that report concise seismological data to a central analysis terminal located within the headquarters. Each station, or det, possesses broadband seismic detection capabilities. Operated on a 24 hour a day basis, each det must detect, record, and analyze all of the seismic activity that occurs. The result of this process is transmitted to headquarters where a determination of the generation mechanism, or source, is made.

GLOBAL SEISMIC OPERATIONS CENTER (GSOC). Known as the B Data Terminal (BDT) or "Zip Room", the GSOC is responsible for both real-time analysis and delayed data processing. Data from North American seismic network stations is received directly from the field via high-speed communications circuits, and is recorded on film for analysis. Data from the remaining network stations and the National Earthquake Information Center (NEIC), is analyzed using the Automatic Data Association and Processing System (ADAPS). This system is covered completely in a subsequent block of instruction.

Hydroacoustic System.

The Hydroacoustic system consists of a worldwide network of ELs that transmit, in digital form, recorded hydroacoustic data (sound waves in water) to a central analysis terminal located within the headquarters. Operated on a 24 hour a day basis, the hydroacoustic data terminal is tasked to identify the source of each recorded wave.

The Hydroacoustic, or Digital "O" System (DOS), is comprised of two separate systems that are interrelated; the Acquisition and Analysis Systems. The Acquisition System presently consists of up to 9 "O" Field Sets (OFS). The Analysis System is more commonly referred to as the Hydroacoustic Recorder and Processor (HRP).

The OFS is a real time data acquisition system designed to collect raw data, perform frequency filtering, data processing, message formatting, and data transmission.

The Analysis System of the DOS is comprised of the HRP. The primary purpose of the HRP is to collect and process data from the OFSs. In order to accomplish these tasks, it is divided into two functional hardware subsystems. The primary subsystem provides data collection, recording, display, analysis, and communication with each OFS. The secondary subsystem serves as back up for the primary in case of failure, at which time it automatically assumes the primary system tasks.

Electromagnetic Pulse System (EMP).

The EMP system consists of a worldwide network of detachments used for detecting, locating, and identifying the source of the Electromagnetic Pulse signals occurring in the atmosphere. This system is comprised of J Field Sets (JFS) that are linked, via dedicated lines to the Central Data Terminal (CDT) located within the headquarters.

The EMP system is a continuously operating electronic technique having the capability to detect, process, and record randomly occurring electromagnetic pulses in the Very Low Frequency (VLF) and High Frequency (HF) spectra.

Data from EMP signals that satisfies priority criterion at the JFS is transmitted in real time to the CDT via a synchronous communication circuit.

The CDT is a continuously operating computer terminal having the capability to receive EMP signal descriptor data from all JFS sites via dedicated communications lines and to perform real time data processing of the incoming data.

The CDT also functions as the central technical control facility for all EMP Technique operations and functions. These operations and functions include: providing output reports; maintaining historical data files; reporting the CDT and JFS status; performing housekeeping functions; and adjusting the operating parameters at all JFS sites.

MISSION CONTRIBUTIONS

The contribution of each of the aforementioned systems is indispensable to mission accomplishment. Although the systems are designed, for the most part, to monitor within a specified media their applications often overlap.

As stated, the airborne systems utilize particulate and gas sampling devices to confirm, and subsequently track, clouds of nuclear debris. Of course, the debris results from the detonation of a nuclear device, however, the test need not occur in the atmosphere. Venting from underground or underwater tests may result in the formation of such clouds. Therefore, the system can substantiate preliminary determinations based on data collected by both the seismic and hydroacoustic systems.

The seismic system is designed to detect minute amounts of ground movement. When an earthquake occurs, waves are generated that propagate away from the source. In order to propagate the waves must cause particle motion, or ground movement, that can be detected. An underground explosion results in the same waves being generated, however discrimination techniques are applied to determine their true source. By utilizing these methods of discrimination, AFTAC is capable of monitoring underground explosions.

The detonation of an explosive device underwater produces sound waves that are recorded with specific envelopes, or characteristic appearances. The observation of this type of wave is the only initial indicator that an underwater test has occurred.

The primary mission of the Hydroacoustic Technique is to supplement the Seismic Technique in detecting, locating, and identifying underwater explosions. A secondary mission is to detect, locate, and identify other underwater phenomena that may be of military significance.

EXERCISE 1

Procedure:

Complete or respond to the following:

1. The first nuclear weapons test was conducted on _______________ at _________________.

2. Name the individual placed in charge of the USSR's version of the "Manhattan Project".

3. The Acheson-Lilienthal report was presented to the UN as the _________________.

4. The yield of underground nuclear weapon tests is limited to 150 KT by the _________________.

5. A fission explosion is often called a/an _______________.

6. Name the three laboratories housed within the MCL.

7. The GMU utilizes a glass trap containing a molecular sieve coated with ____________________.

8. Name the two separate systems that comprise the DOS.

GEOGNOSY

OBJECTIVES

- Given five definitions of terms used in geology, select the definition of geognosy.
- Given an illustration of the Earth, label the major layers.
- Given an illustration of the ocean, label the major layers.
- Given an illustration of the atmosphere, label the major layers.
- Match each of four terms to a statement(s) describing the Geographic Grid Coordinate System.

INTRODUCTION

The study of Earth and its components (land, ocean and atmosphere) is a complicated, yet interesting endeavor. It often begins with a presentation of theories concerning Earth's formation and concludes with speculation about the universe, invariably leaving the most ardent student confused and dismayed. This unit is designed to avoid these undesirable aspects. It acts as an introduction to Geognosy, or "the branch of geology that deals with the constituent parts of the earth, its atmosphere and water, its crust, and the condition of its interior".

The key words in the previous paragraph are "theories" and "speculation". You must realize that in the study of Geognosy many conclusions are based upon indirect observation. Few facts about the Earth, its oceans and atmosphere are determined first hand. Man has yet to devise methods of directly probing the interior of Earth, the depths of the oceans, and heights of the atmosphere, however, excellent and widely accepted models of each do exist and are continually being refined as technology advances.

The following information presents simplistic descriptions of each area covered in geognosy and forms the basis for more in depth study at a later point.

INFORMATION

EARTH STRUCTURE

The study of the Earth is likened to observing an egg. The outward appearance, texture, temperature and composition are easily discerned, however, little is known of its interior from this form of observation. Breaking the egg remedies this dilemma, but another method is required to investigate Earth's interior (i.e., a method of indirect observation).

Our knowledge of the Earth's interior is based, primarily, on the observation of seismic waves. When a seismic disturbance, either a natural earthquake or an underground explosion, occurs, waves are generated that display certain characteristics. The velocity, or speed of travel, of these waves in different materials is known from laboratory experiment. So, if an earthquake occurs at a known time and distance from a recording station scientists can determine the types of materials existing between the two points. Moreover, as seismic waves propagate they change direction, revealing several places within the Earth where changes occur in the physical properties of the materials. These changes could result from differences in composition, atomic structure, or atomic state. The boundary where such changes take place is called a discontinuity.

On the basis of data assembled from studies of the travel habits of seismic waves the earth has been divided into three major zones; crust, mantle, and core.

Crust.

It has been difficult to gather precise data on the Earth's crust from seismic waves originating from earthquakes. Waves from explosions, however, with accurate location and origin times, have filled in most of the details.

The average velocity of waves travelling in the upper region of the crust are similar to the velocity expected for granite, granidiorite, or gneiss. Because these rocks are rich in silica and aluminum we say the material of the upper crust is sialic in composition; the term SIAL, SI for silicon and AL for aluminum, is generally used when speaking of this layer. This layer is only found in the continental regions of the earth and is sometimes referred to as Continental Crust.

A second, more basic layer encircles the entire Earth. Waves travelling in this region display velocities similar to those expected of a wave travelling through basalt. This darker, heavier rock is designated SIMA; SI for silicon and MA for magnesium. This layer is the outermost rock layer under permanent ocean basins and is sometimes referred to as Oceanic Crust.

It is obvious that SIAL is not present in all areas. This fact accounts for differences in the thickness, or depth, of the crust. SIMA reaches to depths of only 5 to 15 km in the ocean basins, while extending up to 100 km deep in continental areas. The weight of the overlying SIAL, or continental crust, causes the SIMA to "sink" deeper into the next region.

Mantle.

Below the Earth's crust is the second major zone, the mantle, which extends to a depth of 2900 km.

Below the discontinuity formed by the bottom of the crust and top of the mantle seismic wave velocity increases drastically. This indicates that the composition of the material suddenly changes. We have no direct evidence of the new material's nature, but the change in speed suggests that it may contain more ferromagnesian minerals than the crust. For many years, most scientists have agreed that the mantle is solid in nature but suspect that it may be capable of flow. This fact appears reasonable at least for the upper portion (the asthenosphere at 200 km) of the mantle. In this region, there are distinct effects on the velocity of certain seismic waves.

What produces this change in the mantle? It may be a rearrangement of atoms under pressure or a change in the kinds of atoms. We do not know exactly, yet. Whatever the new material or state of matter that produces the change, the mantle seems substantially uniform from 600 down to 2900 km.

Core.

We come now to the core, a zone that extends from the bottom of the mantle, at 2900 km, to the center of the earth at 6370 km. Variations in the observation of seismic waves suggest that the core is really a liquid layer 2255 km thick, surrounding a very dense, solid, central sphere 1215 km in radius. Designated the outer core and inner core, respectively, these areas are believed to constitute 30% of the Earth's mass.

More in depth information about the structure of the Earth's interior is presented in subsequent blocks of instruction. Figure 6, however, summarizes the information presented thus far.

OCEAN STRUCTURE

The layers of the ocean are not as clearly defined as that of the Earth. This is due, in part, to the relative ease of its observation and the particular interest of those conducting the study. Biologists determine layers by the type of animal life present at different depths. Oceanographers often classify by differences in temperature. Individuals interested in hydroacoustics, or the propagation of underwater soundwaves, outline layers based on differences in the speed of these waves in water.

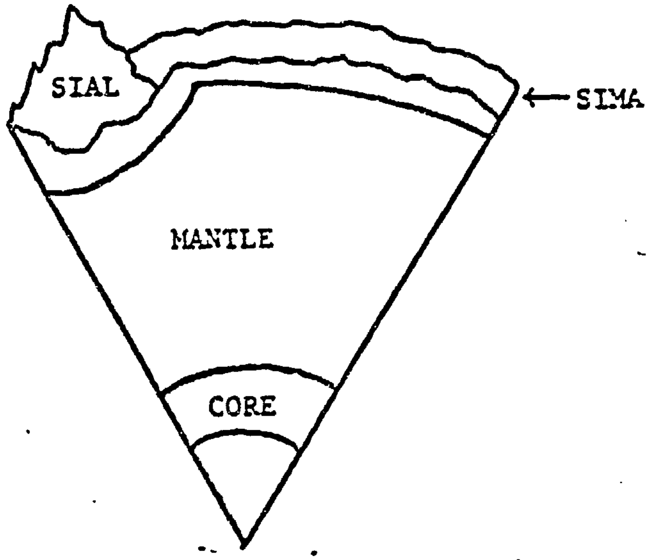


Figure 6
STRUCTURE OF THE EARTH

The speed of a hydroacoustic wave is determined, primarily, by the temperature of the water and pressure. Each of these factors vary with depth. Temperature decreases linearly with depth until a minimum of 3 - 4°C is reached and the speed of sound waves in water decreases drastically with decreasing temperature. Of course, pressure is proportional to depth and sound wave velocity increases with increasing pressure. The interaction of the two forces creates the interesting graph depicted in Figure 7.

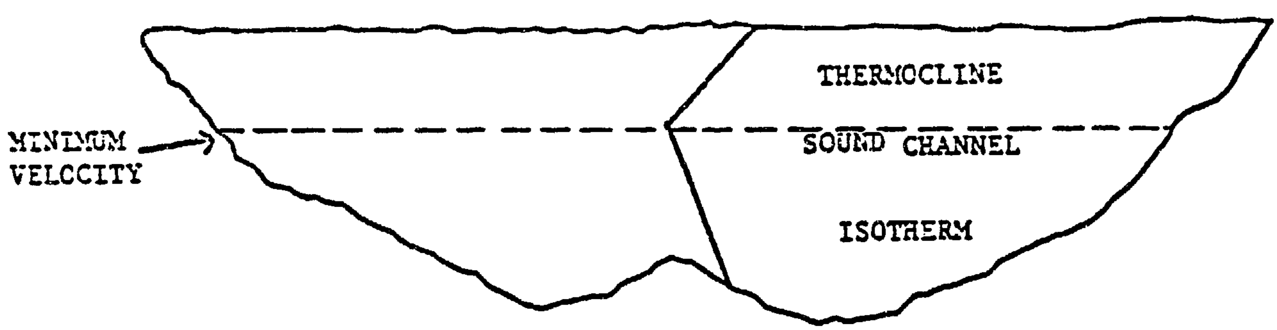


Figure 7
INTERACTION OF PRESSURE AND SOUND VELOCITY

It is apparent that the slowing effect of decreasing temperature outweighs the change in speed (increase) resulting from increased pressure. These combined influences form the basis of hydroacoustic layering.

Thermocline.

The main thermocline is the area in which sound wave speed decreases drastically with decreasing temperature. The depth, or thickness, of the main thermocline is influenced by many things including external mean temperature, seasonal temperature variations, currents, and location in respect to the equator. The temperature constant is reached at a depth of 5000 feet in equatorial waters (mean temperature 82^{O}F) as opposed to very near, or at the surface, in polar regions (mean temperature 30^{O}F). The seasonal variation of external temperature in both regions accounts for migration of up to 100 feet of the temperature constant. Additionally, the cold currents prevalent in the Pacific Ocean cause the constant to present itself at 3500 feet, while the warm currents of the Atlantic delay this to depths of up to 5000 feet.

Sound Channel Axis.

The sound channel axis describes the area of minimum sound wave speed. This region results from the interaction of the effects of temperature and pressure variations and facilitates the propagation of small amounts of sound over long distances. In their book, <u>Elastic Waves in Layered Media,</u> W. Ewing, W. Jardetzky, and F. Press, (McGraw - Hill Book Co. Inc., New York, 1957, page 337) describe the propagation capability of the sound axis in the following manner: "the extremely long range transmission of sound (probably 10,000 miles for small bombs)".

Deep Isothermal Layer.

This layer exists below the sound channel and extends to the ocean bottom. It is marked by constant temperatures, relatively high levels of salinity, and linear velocity increases with increasing pressure.

ATMOSPHERIC LAYERS

The atmosphere of the Earth is divided into five layers and one intermediate region of great importance to the 99105. The existence of these layers and their importance are often taken for granted, if not ignored. The atmosphere exists as a result of the gravitational force of the Earth and the layers are defined by variations in temperature and molecular abundances. Figure 8 depicts these layers.

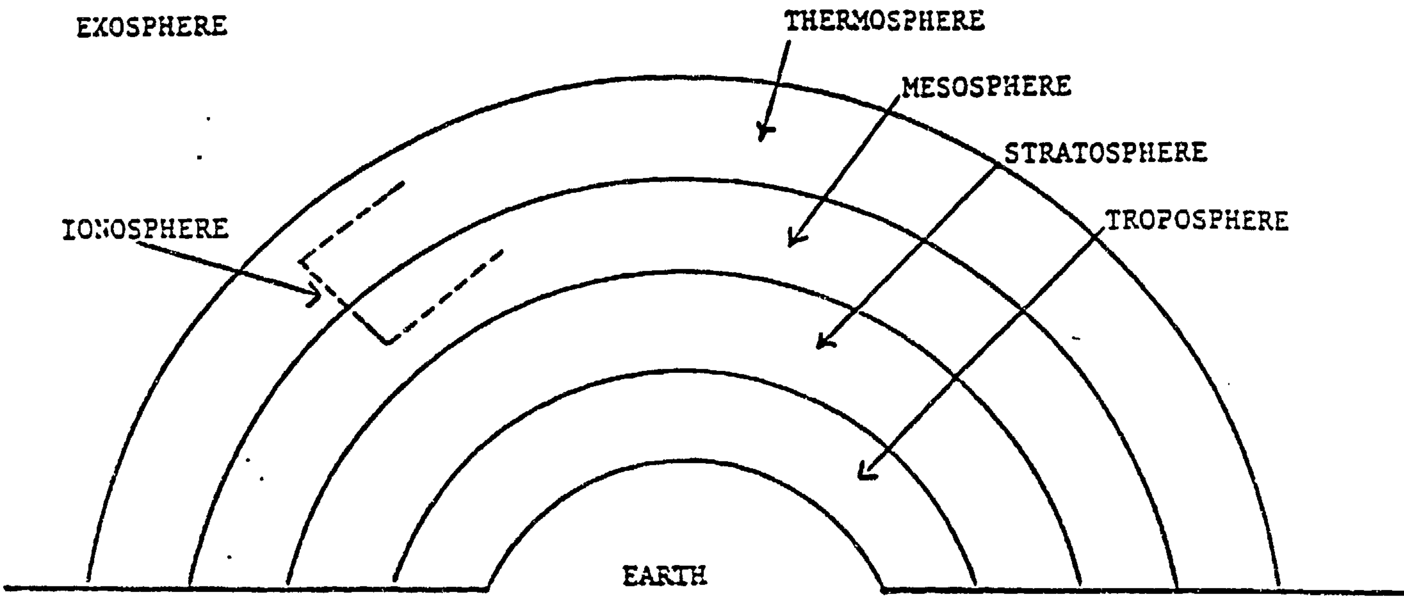


Figure 8
ATMOSPHERIC LAYERS

Troposphere

The troposphere is the first of the layers, and the one man is most familiar with. Extending to heights of approximately 8 km near the poles and 17 km near the equator, this layer is the center of all weather sources. Solar radiation and thermal heating produce convection currents resulting in winds that range from gentle breezes to dangerous hurricane force. The presence of dust particles and the high water vapor content of this region produce clouds and rain. These factors lead to the conclusion that with the exception of mild turbulence in the lower region of the next layer, the troposphere is the only "active" region. The troposphere is distinguished in two other ways. First, it is the only layer that displays a steady decrease in temperature with increasing elevation. This drop, averaging 3½°F for each 1000 feet, is referred to as "lapse rate". In the layers above the troposphere the lapse rate is either positive or negative depending on the layer. Secondly, the troposphere is by far the most dense layer comprising the largest percentage of the mass of the atmosphere.

Stratosphere

The stratosphere extends from the outer limit of the troposphere (8-17 km) to a maximum height of approximately 50 km. This is a fairly stable layer with little, if any, influence on weather. The temperature of this region is determined by solar radiation and its water vapor content is low compared to the troposphere. The presence of an ozone layer near its upper limit is of utmost importance because it absorbs excess amounts of harmful ultraviolet solar radiation. The ozone layer thus possesses a negative lapse rate. Temperatures measured simultaneously above and below the ozone layer are recorded as low as $-100^{\circ}F$ while the temperature of the layer itself may range to $30^{\circ}F$ or $40^{\circ}F$.

Mesosphere

The mesosphere borders the stratosphere and extends to a maximum height of about 80 km. IN this layer, temperature again decreases with altitude to about $-110^{\circ}F$. The major importance of this layer is that it contains the lower portion of the intermediate region called the ionosphere.

Thermosphere

Bordering the mesosphere and climbing to an altitude of about 600 km is the largest of the layers; the thermosphere. The temperature in this layer again increases with altitude and is greatly affected by solar activity and time of day. The remainder of the ionosphere from 80-400 km also falls in this layer and is of prime interest to us.

Ionosphere

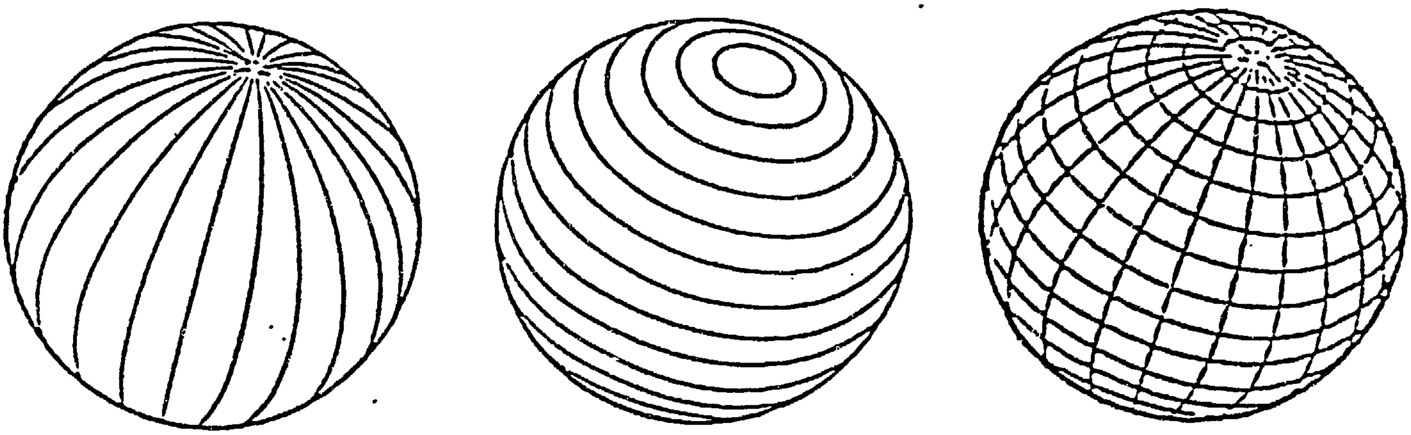
The ionosphere extends from about 60 km to a maximum height of 400 km. As mentioned earlier, this area occupies a position in both the mesosphere and thermosphere. It is unique in that it contains bands of ionized air that reflect radio waves, including those that result from nuclear explosions. These bands of inoization have been given the letter designations D, E, F1, F2, and F, depending upon their location in either day or night.

Exosphere

The exosphere extends above the thermosphere and is a transition zone between the atmosphere and space. Although this area is extremely rarefied, traces of the Earth's atmosphere are still found. This indicates that the boundary between space and the atmosphere is not well defined.

GEOGRAPHIC GRID COORDINATE SYSTEM

The geographic grid coordinate system is merely a method of precisely locating a point on the Earth's surface. Each point is defined by assigning degrees of longitude and latitude. Refer to Figure 9 while reading the following information.



MERIDIANS PARALLELS GRID

Figure 9
GEOGRAPHIC GRID COORDINATE SYSTEM

Grid

The term grid defines the network of lines of longitude and latitude used on a map or globe.

Longitude

The term longitude defines the grids running north and south and converging at the poles. Also referred to as meridians, lines of longitude each scribe one half of a great circle, or the longest direct path around the Earth. They are used to measure distances of up to 180° east and west of the prime meridian (0° longitude). The prime meridian, by international agreement, is the line of longitude extending from pole to pole, and passing through Greenwich England, the former site of the Royal Observatory.

Latitude

The term latitude defines the grids running east and west and parallel to the equator (0° latitude). Also referred to as parallels, lines of latitude are used to measure distances of up to 90° north and south of the equator. The equator is the only grid that scribes a true great circle, or line which if extended to a plane would bisect the Earth. Each of the other parallels decrease progressively in circumference as they move away from 0°.

Degree

As a matter of convention the Earth is considered a sphere. Thus, one degree is equal to the Earth's circumference (24,900 mi) divided by 360°. This distance is expressed as:

$$\frac{24{,}900 \text{ mi}}{360^\circ} = 69 \text{ statute miles (approximately)}$$

$$\frac{40,075\ \text{km}}{360^\circ} = 111 \text{ kilometers (approximately)}$$

It is important to note that the lines of longitude do converge and the distance of 1° of longitude is reduced to approximately one half or 34½ miles (55½ km) at 60° north and south.

Each degree is further divided into minutes and seconds.

MINUTE. Each minute is equal to one sixtieth of a degree. Therefore, this number is expressed as:

$$\frac{69\ \text{mi}}{60} = 1.15 \text{ statute miles (approximately)}$$

or

$$\frac{111\ \text{km}}{60} = 1.85 \text{ kilometers (approximately)}$$

SECOND. Each second is equal to one sixtieth of a minute. Therefore, this number is expressed as:

$$\frac{1.15\ \text{mi}}{60} = .02 \text{ statute miles (approximately)}$$

or

$$\frac{1.85\ \text{km}}{60} = .03 \text{ kilometers (approximately)}$$

Location.

Locating a point on the Earth's surface becomes an easy task when the geographic grid coordinate system is used. For example, the coordinates of Boulder, Wyoming are 46° 34' 02" N by 109° 34' 57" W. These coordinates, read 46 degrees, 34 minutes, 2 seconds north by 109 degrees, 34 minutes, and 57 seconds west, reveal the approximate location of this small town with just a cursory glance at a globe. (Note that latitude is <u>always</u> stated first).

EXERCISE 2

Procedure:

Complete or respond to the following:

1. Name the two layers of Earth's crust.

2. What is the radius of Earth? ____________ km.

3. Name three factors affecting the thickness of main thermocline.

4. The layer below the sound channel axis is termed the ____.

5. The troposphere extends to a height of ________________ kms near the equator.

6. The Ozone layer has a __________________ lapse rate.

7. One degree is equal to ______________________ divided by ______________________.

8. Record the approximate coordinates of each of the following locations:

Nome, Alaska, USA

________________ ________________

Peiping, China

________________ ________________

Sydney, Australia

________________ ________________

WAVE PROPAGATION

OBJECTIVES

- o Given five statements describing phenomena associated with geognosy, select those statements relating to wave propagation.
- o Given three illustrations associated with different types of particle motion and seven descriptive phrases and terms, associate the phrases and terms with the appropriate illustration(s).
- o Complete five statements explaining the mechanics of wave propagation.
- o Given a list of three physical properties of gaseous, liquid, and solid media, match each property to a statement(s) describing its affect on wave propagation.

INTRODUCTION

From previous units of instruction it is known that three of the monitoring systems utilized by AFTAC are designed to detect waves generated by the detonation of a nuclear device. Each system, the seismic, hydroacoustic, and EMP, operates in a separate medium giving rise to the question of how waves propagate in each media. To answer this question we will review the states of matter, define the properties of a wave, describe the particle motion associated with principal wave types, and discuss the mechanics of wave propagation. Finally, we will study the physical properties of each media and how these properties affect wave propagation.

INFORMATION

NATURE OF MATTER

Matter exists in three states: solids, liquids, and gasses. A solid is a substance that displays a definite shape and definite volume. A liquid takes the shape of its container and has a definite volume. A gas takes the shape of its container and has the same volume as the container.

The molecules of a solid are fixed in relation to each other. They do vibrate back and forth through their position of equilibrium but are so close together that they can be compressed only slightly. Solids are normally crystalline substances, that is their molecules are arranged in a definite pattern. Because of this solids tend to hold their shape and have a definite volume.

The molecules of a liquid are not fixed in relation to each other. They normally move in a flowing motion but are still so close together that they are practically incompressible, thus have a definite volume. Because the molecules move in a smooth, flowing motion and not in any fixed manner, a liquid takes the shape of its container.

The molecules of a gas are not fixed in relation to each other and move rapidly in all directions, colliding with each other. They are much farther apart than the molecules of a liquid, and extremely far apart when compared to the molecules of a solid. The movement of gas molecules is limited only by its container, therefore, a gas takes the shape of its container. Because the molecules are far apart, a gas is easily compressed and has the same volume as its container.

PROPERTIES OF WAVES

A wave is simply a disturbance that travels through a medium. This disturbance may be a displacement of atoms from their equilibrium positions in any elastic medium, a variation in pressure in a gas, or more simply a pulse sent along a rope that is fixed at one end. In any case, a wave represents a transfer of energy in the direction of propagation of the disturbance. A wave may be a single pulse disturbance, like the sound heard when one claps their hands, or a wave train. A wave train results when the source is periodic, like the sound heard when an entire audience applauds. Regardless of the source there are certain characteristics of waves that, for the sake of convention, require definition. (Refer to Figure 10).

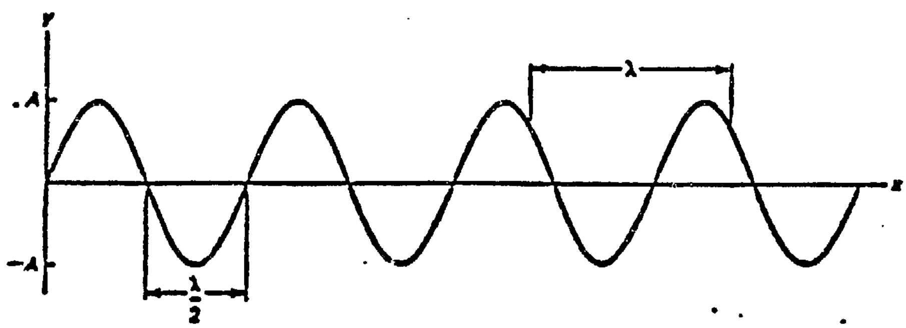


Figure 10
WAVE TRAIN CHARACTERISTICS

Characteristics

The amplitude of a wave (A) is the maximum displacement possible when measuring peak to trough. The wavelength, (lamda), is the length of the period of the disturbance pattern, normally a metric unit of length. The period (T) is the time required for a wavelength to pass a point on the x-axis. The reciprocal of the period (1/T) is called the frequency (f) of the wave, and is the number of complete oscillations per unit of time. One oscillation per second is called a hertz (Hz) or cycle per second (cps). The velocity (v) of propagation of a wave is the wavelength divided by the period and is expressed:

$$v = \frac{\lambda}{T} \quad \text{or} \quad \lambda f$$

The value obtained from this formula is the speed that the disturbance is moving along the x-axis; it also represents the speed that energy is being transmitted along the x-axis. It must be emphasized that no medium is transferred by the wave, only energy. Matter may move about an equilibrium point but there is no net transfer of matter. This is visualized by observing a bouy in the ocean. The bouy bobs up and down as the waves pass, but does not move horizontally. The energy has been transmitted, not the matter.

Waves are generally divided into two categories, longitudinal and transverse. A longitudinal wave is one in which the displacement (particle motion) is in line with the direction of propagation and therefore, direction of energy transfer. A transverse wave is one in which the particle motion is perpendicular, or at right angles to the direction of wave propagation. More in depth study of particle motion is provided later, however, it is important to restate that there is no net transfer of material, only energy, associated with both wave types.

Waves exhibit a quality referred to as superposition. As two waves simultaneously pass through a region they merge to form a new wave in that region.

Waves that are in phase when passing through a given region combine to produce a wave with a greater displacement (A) while the period (T) remains constant. This is referred to as CONSTRUCTIVE INTERFERENCE and is illustrated in Figure 11.

Waves that are one half wavelength (180°) out of phase combine to produce a wave with no displacement, effectively cancelling each other. This is referred to as DESTRUCTIVE INTERFERENCE and is illustrated in Figure 12.

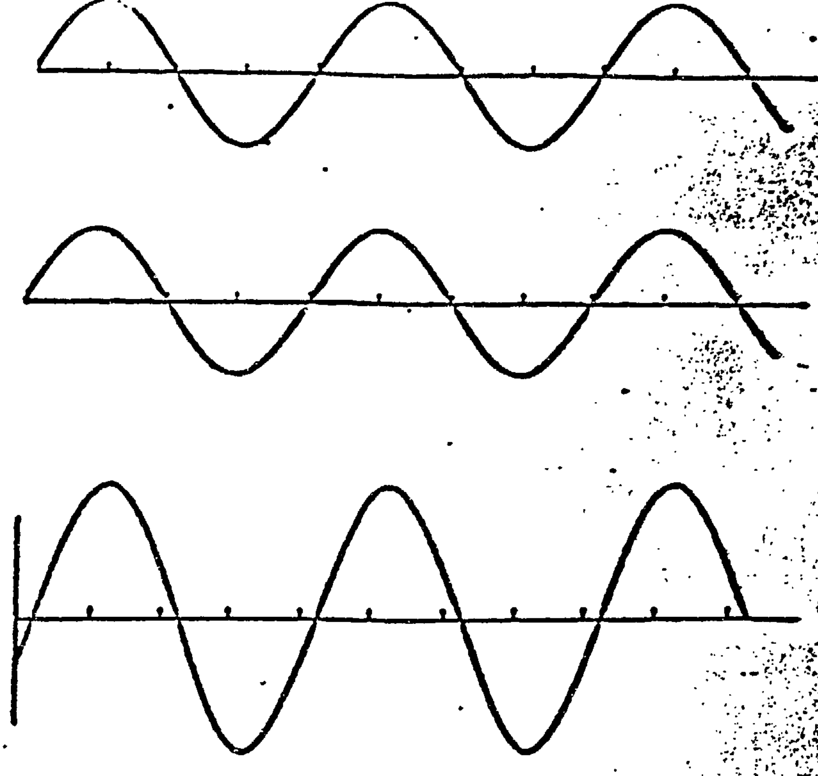


Figure 11
CONSTRUCTIVE INTERFERENCE

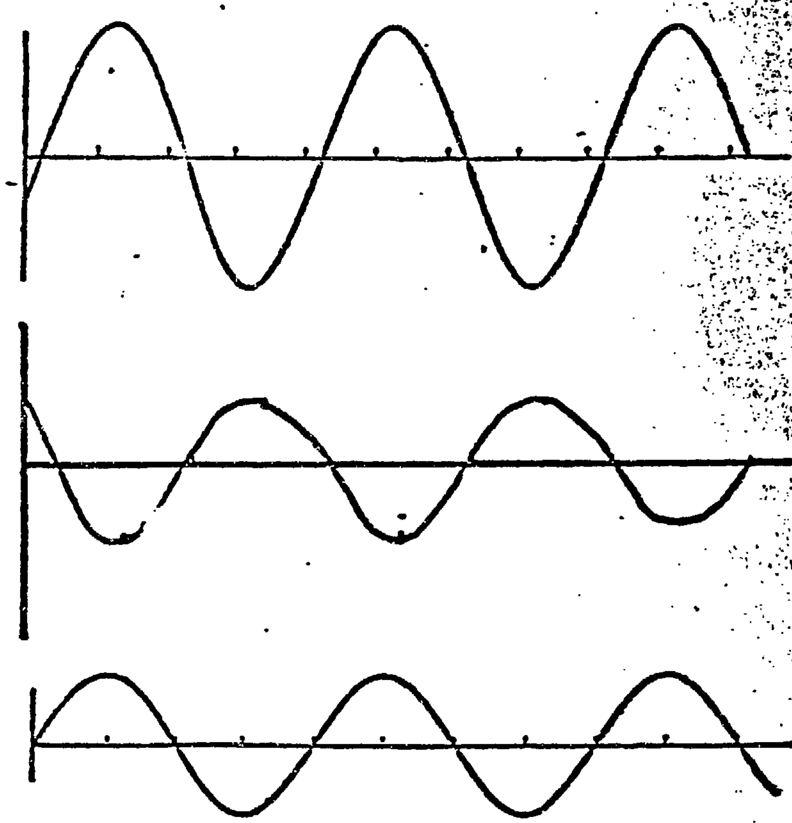


Figure 12
DESTRUCTIVE INTERFERENCE

Waves from a periodic source, such as a seismic disturbance, undergo these processes many times and are therefore very complex in their appearance.

PARTICLE MOTION

As stated earlier, waves are classified by the particle motion, or observed molecular movement, the disturbance causes. Longitudinal, transverse, and elliptical retrograde are the three classifications most important to the study of detection systems.

Longitudinal.

As a disturbance passes through a medium the individual molecules are set in motion about their normal rest, or equilibrium, position. A longitudinal wave causes this vibration to be in line with, or parallel to, the direction of wave propagation. Refer to Figure 13.

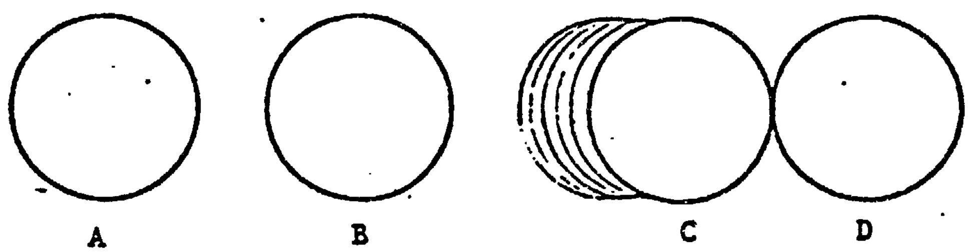


Figure 13
LONGITUDINAL WAVEFRONT

This illustration depicts the passing of a longitudinal wavefront (x) through a solid medium. Molecules A and B have already transferred the energy associated with the wavefront and continue to oscillate through their respective rest positions. The inertia of the energy transfer from molecule B to molecule C has caused C to overshoot its normal rest position and strike molecule D. The energy is subsequently transferred to D and the wave continues to propagate in this fashion.

Longitudinal particle motion is referred to by many names, all describing the observed molecular motion. A few of the alternate names are: compressional-rarefactional, compressionaldialational, and push-pull. Figure 13 is a common illustration of longitudinal particle motion. Note that a slight change in volume occurs.

Transverse.

Transverse waves result in the displacement of molecules perpendicular to the direction of wave propagation. That is to say that the particles move at right angles to the disturbance. This phenomena is easily illustrated by securing one end of a length of rope, stretching it taut, and quickly jerking the free end. The resulting motion in the rope is actually a transverse wave. Figure 14 illustrates this type of wave.

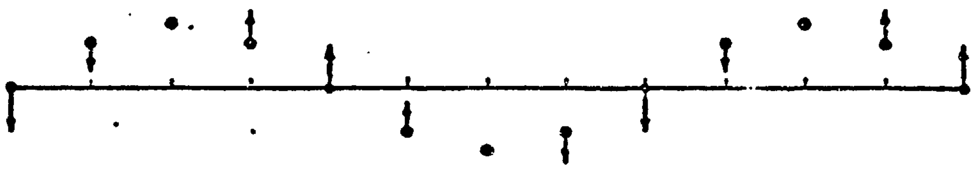


Figure 14
TRANSVERSE WAVE

In nature this wave results from the release of a shearing, or twisting, force that has been applied to a substance. However, unlike the longitudinal wave, transverse waves propagate only in solids. The shear elasticity of fluids, or matter in which the attractive forces between molecules permits flow (liquids and gasses), is insufficient to support this type of wave.

Many terms are used to describe the transverse wave. Shear is most common, and describes the type of force that generates the wave. Equivoluminous and transverse both describe the particle motion associated with the disturbance. Figure 15 is a common illustration of a transverse wave. Note that there is no change in volume, simply shape.

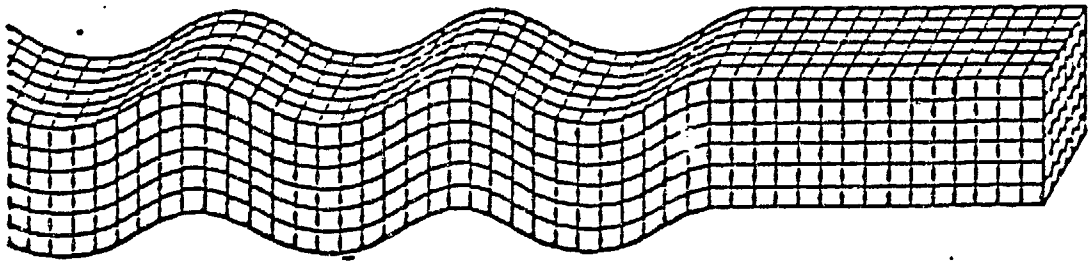


Figure 15
TRANSVERSE WAVE MOTION

Elliptical Retrograde.

The particle motion associated with this type of wave is depicted in Figure 16. Note both the horizontal and vertical motion of the particles. This wave, commonly referred to as Rayleigh, is only observed on seismological records and further discussion is deferred to units of instruction dealing with seismology.

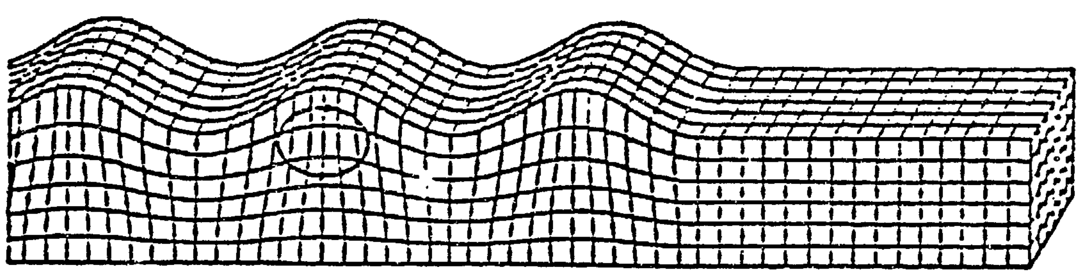


Figure 16
ELLIPTICAL RETROGRADE MOTION

The information presented thus far makes it obvious that the Earth and its constituent parts are not homogeneous mediums, meaning they are not comprised of the same materials throughout and are therefore layered. This layering has definite effects on wave propagation. A wave generated in a homogeneous substance will not change in appearance despite the distance travelled, however, layering has drastic effects on wave appearance.

When a wave is incident upon, or strikes, the interface between two mediums, a portion of the wave may enter the new medium and change direction. This portion of the wave is said to refract. That portion of the wave that strikes the interface but remains in the medium is said to reflect.

Reflection.

The law of reflection requires the angle of reflection to equal the angle of incidence. The angle of incidence, ϕ_i ; is the angle the wave makes with a normal, or a line perpendicular to the interface between two layers. The angle of reflection, ϕ_r ; is the angle the reflected wave makes with the normal to the interface. These facts are illustrated in Figure 17.

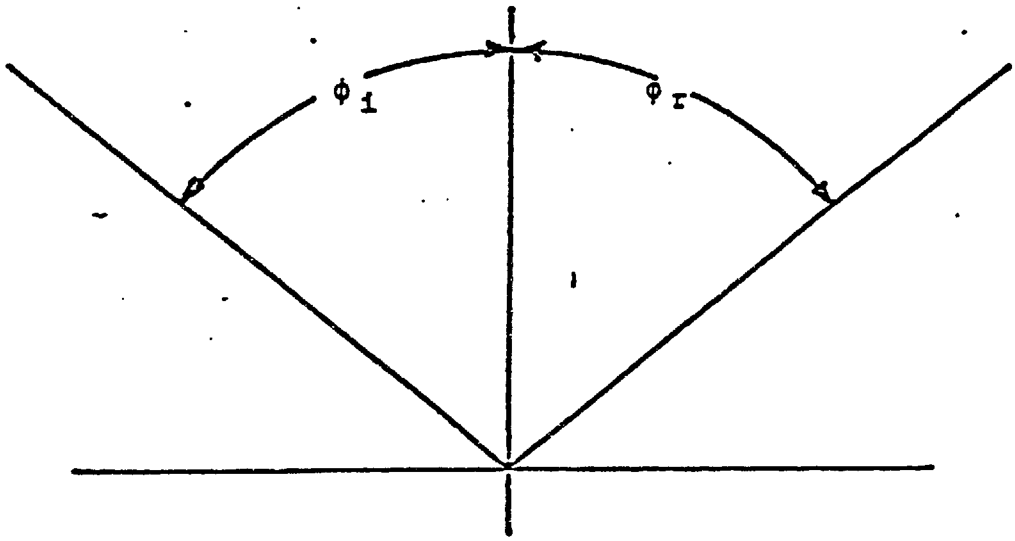


Figure 17
ANGLE OF REFLECTION

If the wave is travelling from a medium that is denser to a less dense medium, the reflected wave remains in phase with the incident wave. If the wave is travelling from a less dense to a denser medium the reflected wave is out of phase with the incident wave. These phenomena can be demonstrated with a rope. If one end is left free and a pulse (wave) is sent along the rope, the free end responds with increased displacement, like a bullwhip. When the wave arrives at the free end the reflected wave is in phase and contructive interference results. If the end of the rope is secured to a heavier rope, or chain, the reflected wave is out of phase with the incident wave and destructive interference occurs.

Refraction.

That portion of a wave that enters the new medium and is transmitted through it is said to be refracted. Refraction obeys Snell's Law, that states mathematically, a wave travelling from a denser medium to a less dense medium is refracted away from the normal with the interface. A wave travelling from a less dense to a denser medium is refracted toward the normal with the interface. This is illustrated in Figure 18.

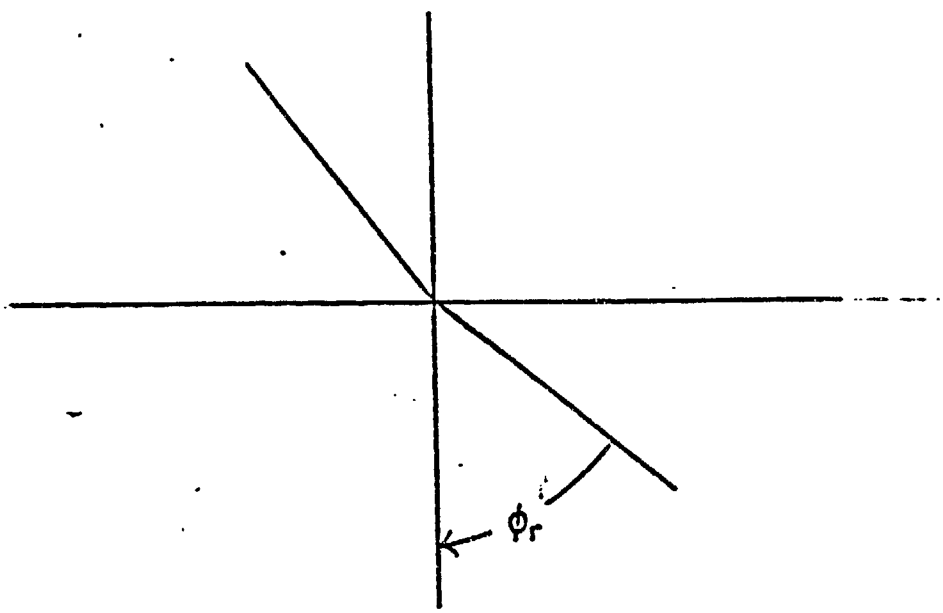


Figure 18
ANGLE OF REFRACTION

Diffraction.

As the angle of incidence of a wave approaches 90° the wave is neither reflected nor refracted but diffracted. The wave, in essence, does not reflect but attempts to travel around what it sees as an obstacle. If you place a rock in a stream of water, the water flows around the obstacle. Of course, this is a simple analogy of a complex problem, but it does illustrate diffraction. Figure 19 depicts the phenomena of diffraction.

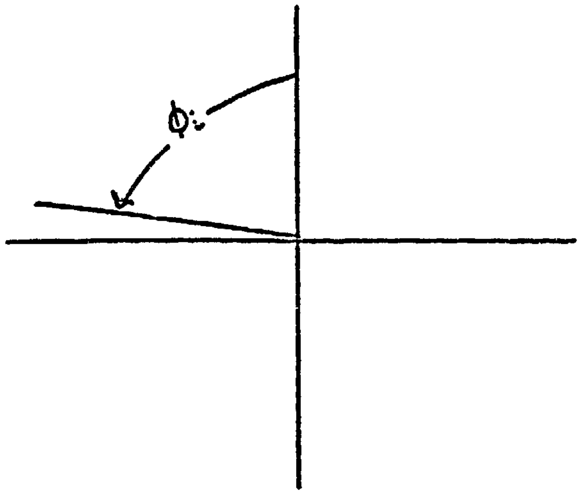


Figure 19
DIFFRACTED WAVE

PHYSICAL PROPERTIES OF MATTER

Our earlier discussions were limited to types of matter, properties of a wave, and the particle motion associated with different wave types. But, the study of detection systems requires more. After all, we are concerned with detecting waves generated by explosions.

By this time, you must have realized that there is a lot more to wave propagation than simply a disturbance travelling through a substance. You may be asking questions like this . . . Do all states of matter possess the same physical properties? Do these physical properties affect wave propagation? Are these factors interrelated? This material is designed to answer these questions and more.

Solids.

As stated, solids have a definite shape and definite volume. Additionally, the molecules of a solid are normally arranged in a definite pattern (crystalline). Moreover, most solids display certain properties (i.e., density, elasticity).

DENSITY. Density, a property of all matter, is defined as the mass per unit volume and is expressed:

$$D = \frac{m}{v}$$

where D is the density
m is the mass, and
v is the volume

Density is normally expressed in Kg/m^3. Generally speaking, the density of a material decreases as temperature increases and increases as temperature decreases.

ELASTICITY. All objects become deformed when an outside force is applied and changes its shape or size. The objects ability to return to its original shape and size after removing the force is called elasticity. When force is applied, the molecules of a solid either repel or attract each other. For instance, if a rubber ball is pulled out of shape and then released, the ball returns to its original shape. The attractive forces of the molecules cause this. Conversely, if the ball is squeezed and released the ball again returns to its original shape. By squeezing the ball its molecules have been forced too closely together and they repel each other. In summary, if the molecules of a solid are slightly pulled apart they attract each other and if compressed they repel each other.

If too great a force is applied, a solid can not return to its original size and shape. When this occurs the elastic limit of the object has been exceeded. For instance, if a spring is stretched beyond its elastic limit it can not return to its original shape. The molecules of the spring have been pulled far enough apart that their normal attractive forces cannot return the spring. If too much tension is applied the spring breaks. These facts are illustrated in Figure 20.

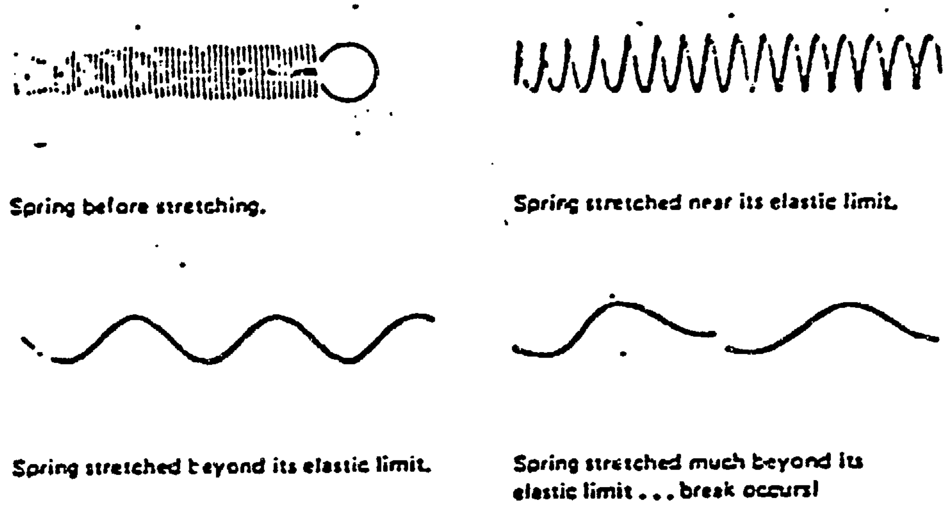


Figure 20
ELASTICITY

Elasticity is measured in a number of ways. Whenever an object is deformed by an outside force the molecular forces of the object tend to resist the change in shape and/or volume. Stress is a measure of the tendency of an object to return to its original shape and size after a deforming force is removed. There are five basic stresses: tension, compression, shear, twisting and bending. Each form of stress is illustrated in Figure 21. More specifically, stress is defined as the ratio of the outside applied force that causes the distortion to the area over which the force acts. This is expressed by the following formula:

$$\text{stress} = \frac{\text{applied force}}{\text{area over which the force acts}}$$

or

$$S = \frac{F}{A}$$

where S if the stress
F is the force, and
A is the area over which the force acts.

The metric stress unit is usually the pascal (Pa) and is expressed:

$$1\text{Pa} = 1\text{N/m}^2 \qquad (1\text{N} = .225 \text{ lb})$$

where:

N is the weight of an object in Newtons,
and m^2 is the area acted upon in square meters.

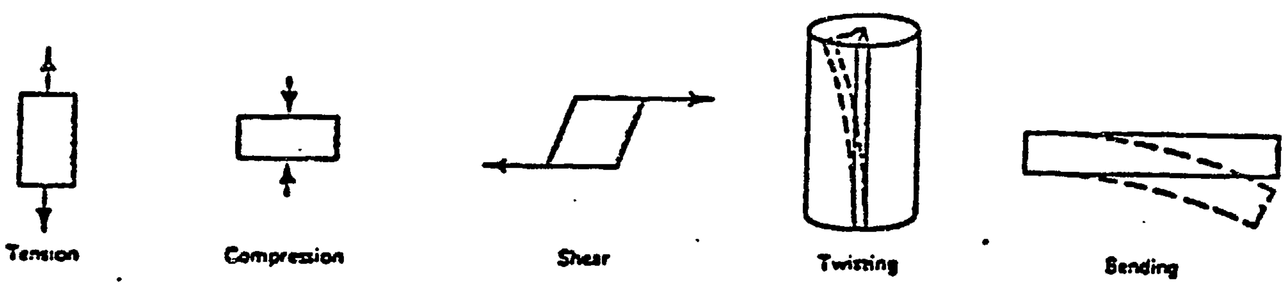


Figure 21
FORMS OF STRESS

Whenever stress is applied to an object the object is deformed. The resulting deformation is called strain. That is, strain is the relative amount of deformation of a body that is under stress. Strain is a measure of the change in length per unit of length, change in volume per unit of volume, and so on. Simply stated, strain is a direct consequence of stress.

PRESSURE. When force acts perpendicular to a surface, the pressure exerted on the surface is given by the formula:

$$P = \frac{F}{A}$$

where P is the pressure
F is the force, and
A is the area of the surface.

Pressure, like stress, is measured in pascals.

Examination of the given formula shows that a decrease in area, with equal force applied, results in dramatic increases in pressure.

ELASTIC MODULUS. A basic law relating to the elasticity of solids is Hooke's Law that states "stress is directly proportional to strain as long as the elastic limit has not been exceeded". In other words, strain continues to increase proportionally with stress. Beyond this point (elastic limit), the material is permanently deformed; with further stress applied the material finally breaks. This proportionality constant between stress and strain is termed the elastic modulus and is stated:

$$\text{stress} = (\text{elastic modulus}) \times (\text{strain})$$

or

$$\text{elastic modulus} = \frac{\text{stress}}{\text{strain}}$$

This formula is applicable to all types of stress.

BULK MODULUS. The volume of any substance is decreased when subjected to pressure. As an object is lowered into the ocean, pressure is exerted equally on all sides. The pressure increases proportionally with depth and so does the object's reduction in volume. This change in volume is expressed as a variation in Hooke's law and is stated:

$$\text{stress} = (\text{elastic modulus}) \times (\text{strain})$$

where the elastic modulus is called the "bulk modulus" and is represented by β (beta). The stress is the change in force per unit area (pressure) and strain is the change in volume per unit of volume ($\Delta V/V$). Knowing this, the bulk modulus of volume elasticity may be expressed:

$$\beta = \frac{\text{stress}}{\text{strain}} = \frac{\Delta F/A}{-\Delta V/V} = \frac{\Delta P}{-\Delta V/V}$$

Again, as long as the elastic limit of the material is not exceeded it returns to its original shape and size when the external force is removed.

COMPRESSIBILITY. The compressibility, c, of a material is the reciprocal of its bulk modulus or:

$$c = \frac{1}{\beta}$$

SHEAR MODULUS. When the shape of an object is changed by applying equal force in parallel and opposite directions, the object is being "sheared". This is easily illustrated by placing a book on a table top then pushing the top and bottom covers in opposite directions. Refer to Figure 22. As the shearing force is applied the pages slide past one another and the book takes the shape of a parallelogram. Note that no change occurs in the volume.

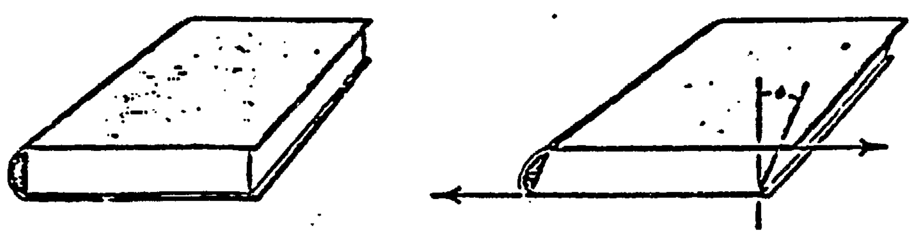


Figure 22
SHEARING ACTION

The shearing stress is defined as the change in force per unit area ($\Delta F/A$) and the shearing strain as the amount of lateral displacement per unit height (x/h). This is yet another variation of Hooke's Law and is stated:

stress = (elastic modulus) x (strain)

where the elastic modulus is called the shear modulus. Therefore, the shear modulus (S) may be expressed

$$S = \frac{\text{stress}}{\text{strain}} = \frac{\Delta F/A}{x/h}$$

The effect of these forces on the propagation of a wave is easily understood by examining the formula for the velocity of seismic waves.

The velocity of the compressional wave (V_p) is determined by the formula

$$V_p = \sqrt{(\beta + 4/3\ S)/\rho}$$

where β is bulk modulus, S is shear modulus, and ρ is the density of the medium.

Gases.

EXPANSION. Expansion is the property of a gas that causes it to completely occupy the volume of its container.

DIFFUSION. Diffusion is the property of a gas that allows it to combine with the molucules of a solid or liquid.

A balloon inflates because of the pressure of gas molecules on the inside surface of the balloon. This pressure results from the collision of the rapidly moving molecules with the walls of the balloon. The pressure may be increased by blowing into the balloon or heating the molecules present. Heat increases the velocity of the molecules.

Liquids

A liquid is a substance that has definite volume and assumes the shape of its container. The molecules move in a flowing motion but are so close together that they are difficult to compress.

VISCOSITY. One characteristic of liquids is called flow. In liquids there is friction, called viscosity. The greater the molecular attraction, the greater the friction and the greater the viscosity.

If a liquids temperature is increased, its viscosity decreases. An increase in temperature causes an increase in the distance between molecules, reducing the molecular attraction.

COHESION. The attractive forces between like molecules causes a liquid to be sticky.

ADHESION. The attractive force between unlike molecules is called adhesion.

A liquid whose adhesive forces are greater than its cohesive forces tends to leave wet any surface it comes in contact with. A liquid whose cohesive forces are greater than its adhesive forces leaves dry any surface it comes in contact with.

EXERCISE 3

Procedure:

Complete or respond to the following:

1. The molecules of a liquid ________________ fixed in relation to each other.

2. A wave train results when the source is_________________.

3. A longitudinal wave causes particle motion _____________ to the direction of propagation.

4. What are two alternate names for transverse particle motion?

5. The law of reflection requires 0_i to equal the __________ ____.

6. Diffraction occurs when 0_i approaches _________________.

7. How is density defined?

8. How is strain defined?

9. The metric unit of stress is usually the ______________.

10. When the elastic limit of a material is exceeded the material ______________________________.