

CAMPBELL BIOLOGY BIOMOLECULES CHAPTER US OUTLINE

CAMPBELL BIOLOGY BIOMOLECULES CHAPTER US OUTLINE PROVIDES A COMPREHENSIVE EXPLORATION INTO THE FUNDAMENTAL BUILDING BLOCKS OF LIFE. THIS DETAILED GUIDE DELVES INTO THE FOUR MAJOR CLASSES OF ORGANIC MOLECULES ESSENTIAL FOR CELLULAR FUNCTION: CARBOHYDRATES, LIPIDS, PROTEINS, AND NUCLEIC ACIDS. UNDERSTANDING THESE BIOMOLECULES IS PARAMOUNT FOR GRASPING THE INTRICATE PROCESSES OF BIOLOGY, FROM CELLULAR RESPIRATION TO GENETIC INHERITANCE. WE WILL DISSECT THEIR STRUCTURES, FUNCTIONS, AND THE KEY REACTIONS THAT GOVERN THEIR ROLES WITHIN LIVING ORGANISMS, OFFERING A ROBUST FRAMEWORK FOR STUDENTS AND ENTHUSIASTS ALIKE. THIS ARTICLE SERVES AS AN IN-DEPTH BREAKDOWN OF THE CHAPTER'S CONTENT, ENSURING A THOROUGH UNDERSTANDING OF THESE VITAL ORGANIC COMPOUNDS.

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THE MOLECULES OF LIFE: AN OVERVIEW

LIFE AS WE KNOW IT IS BUILT UPON A FOUNDATION OF COMPLEX ORGANIC MOLECULES, OFTEN REFERRED TO AS BIOMOLECULES. THESE MOLECULES ARE CARBON-BASED COMPOUNDS THAT ARE SYNTHESIZED BY LIVING ORGANISMS. THEY ARE INCREDIBLY DIVERSE, FULFILLING A VAST ARRAY OF ROLES ESSENTIAL FOR SURVIVAL, GROWTH, REPRODUCTION, AND ADAPTATION. THE STUDY OF THESE BIOMOLECULES IS CENTRAL TO UNDERSTANDING CELLULAR PROCESSES, METABOLIC PATHWAYS, AND THE VERY ESSENCE OF WHAT IT MEANS TO BE ALIVE. CAMPBELL BIOLOGY DEDICATES SIGNIFICANT ATTENTION TO THESE MACROMOLECULES BECAUSE THEIR INTRICATE STRUCTURES DIRECTLY DICTATE THEIR DIVERSE AND CRITICAL FUNCTIONS WITHIN ALL LIVING SYSTEMS.

THE FOUR MAJOR CLASSES OF ORGANIC MOLECULES THAT FORM THE BASIS OF LIFE ARE CARBOHYDRATES, LIPIDS, PROTEINS, AND NUCLEIC ACIDS. WHILE THEY SHARE A COMMON CARBON BACKBONE, THEIR UNIQUE ARRANGEMENTS OF ATOMS AND FUNCTIONAL GROUPS LEAD TO VASTLY DIFFERENT PROPERTIES AND ROLES. FOR INSTANCE, CARBOHYDRATES ARE PRIMARILY FOR ENERGY, PROTEINS FOR DIVERSE FUNCTIONS INCLUDING CATALYSIS AND STRUCTURE, LIPIDS FOR ENERGY STORAGE AND MEMBRANE FORMATION, AND NUCLEIC ACIDS FOR GENETIC INFORMATION STORAGE AND TRANSFER. EACH CLASS IS A VAST REALM OF STUDY, WITH COUNTLESS VARIATIONS AND SPECIALIZED ROLES WITHIN DIFFERENT ORGANISMS AND CELLULAR ENVIRONMENTS.

CARBOHYDRATES: ENERGY SOURCES AND STRUCTURAL COMPONENTS

CARBOHYDRATES ARE A FUNDAMENTAL CLASS OF BIOMOLECULES, CHARACTERIZED BY THE GENERAL FORMULA $(CH_2O)_n$. THEY ARE OFTEN REFERRED TO AS SUGARS, STARCHES, OR SACCHARIDES, AND THEY SERVE AS PRIMARY ENERGY SOURCES FOR MOST ORGANISMS, AS WELL AS PLAYING CRUCIAL ROLES IN CELLULAR STRUCTURE AND RECOGNITION. THE SIMPLEST CARBOHYDRATES

ARE MONOSACCHARIDES, WHICH CAN BE LINKED TOGETHER TO FORM LARGER, MORE COMPLEX CARBOHYDRATES. THEIR VERSATILITY IN BOTH ENERGY PROVISION AND STRUCTURAL SUPPORT MAKES THEM INDISPENSABLE TO LIFE.

MONOSACCHARIDES: THE SIMPLE SUGARS

MONOSACCHARIDES ARE THE SIMPLEST FORM OF CARBOHYDRATE AND ARE KNOWN AS SIMPLE SUGARS. THEY ARE THE MONOMERS FROM WHICH ALL LARGER CARBOHYDRATES ARE BUILT. THE MOST COMMON MONOSACCHARIDES IN BIOLOGY ARE GLUCOSE, FRUCTOSE, AND GALACTOSE. GLUCOSE IS A SIX-CARBON SUGAR (A HEXOSE) AND IS THE PRIMARY FUEL SOURCE FOR MOST CELLS, CENTRAL TO CELLULAR RESPIRATION. FRUCTOSE, ALSO A HEXOSE, IS COMMONLY FOUND IN FRUITS, AND GALACTOSE IS A COMPONENT OF MILK SUGAR. THESE SIMPLE SUGARS TYPICALLY EXIST AS RING STRUCTURES IN AQUEOUS SOLUTIONS, WHICH ARE MORE STABLE THAN THEIR OPEN-CHAIN FORMS.

DISACCHARIDES: COMBINING SIMPLE SUGARS

DISACCHARIDES ARE FORMED WHEN TWO MONOSACCHARIDES ARE JOINED TOGETHER BY A GLYCOSIDIC LINKAGE THROUGH A DEHYDRATION REACTION. THIS PROCESS INVOLVES THE REMOVAL OF A WATER MOLECULE. COMMON DISACCHARIDES INCLUDE SUCROSE (TABLE SUGAR), WHICH IS COMPOSED OF GLUCOSE AND FRUCTOSE; LACTOSE (MILK SUGAR), MADE OF GLUCOSE AND GALACTOSE; AND MALTOSE (MALT SUGAR), FORMED FROM TWO GLUCOSE UNITS. THESE DISACCHARIDES ARE IMPORTANT DIETARY COMPONENTS AND SERVE AS READILY AVAILABLE ENERGY SOURCES FOR ORGANISMS.

POLYSACCHARIDES: COMPLEX CARBOHYDRATES

POLYSACCHARIDES ARE LONG CHAINS OF MONOSACCHARIDES, OFTEN NUMBERING IN THE THOUSANDS. THEY CAN BE EITHER STORAGE MOLECULES OR STRUCTURAL COMPONENTS. STORAGE POLYSACCHARIDES IN PLANTS INCLUDE STARCH, WHICH IS A MIXTURE OF AMYLOSE (UNBRANCHED GLUCOSE CHAINS) AND AMYLOPECTIN (BRANCHED GLUCOSE CHAINS), USED TO STORE ENERGY. IN ANIMALS, GLYCOGEN SERVES A SIMILAR PURPOSE, WITH A MORE HIGHLY BRANCHED STRUCTURE THAT ALLOWS FOR RAPID RELEASE OF GLUCOSE WHEN ENERGY IS NEEDED, PRIMARILY STORED IN THE LIVER AND MUSCLES. STRUCTURAL POLYSACCHARIDES INCLUDE CELLULOSE, THE MAIN COMPONENT OF PLANT CELL WALLS, WHICH PROVIDES RIGIDITY AND SUPPORT, AND CHITIN, FOUND IN THE EXOSKELETONS OF INSECTS AND CRUSTACEANS, AS WELL AS IN FUNGAL CELL WALLS.

LIPIDS: DIVERSE HYDROPHOBIC MOLECULES

LIPIDS ARE A DIVERSE GROUP OF MOLECULES THAT ARE CHARACTERIZED BY THEIR HYDROPHOBIC (WATER-REPELLING) NATURE. THIS PROPERTY ARISES FROM THEIR PREDOMINANTLY NONPOLAR HYDROCARBON CHAINS. WHILE NOT TRUE POLYMERS IN THE SAME SENSE AS CARBOHYDRATES, PROTEINS, AND NUCLEIC ACIDS, LIPIDS ARE STILL LARGE ORGANIC MOLECULES ESSENTIAL FOR LIFE. THEY PLAY CRITICAL ROLES IN ENERGY STORAGE, INSULATION, PROTECTION OF ORGANS, AND FORMING THE STRUCTURAL BASIS OF CELL MEMBRANES. THEIR INSOLUBILITY IN WATER MAKES THEM DISTINCT FROM THE OTHER MAJOR CLASSES OF BIOMOLECULES.

FATS AND OILS: ENERGY STORAGE AND INSULATION

FATS AND OILS ARE TRIGLYCERIDES, WHICH ARE ESTERS FORMED FROM GLYCEROL AND THREE FATTY ACIDS. GLYCEROL IS A THREE-CARBON ALCOHOL, AND A FATTY ACID IS A LONG HYDROCARBON CHAIN WITH A CARBOXYL GROUP AT ONE END. THE TYPE OF FATTY ACIDS DETERMINES WHETHER THE LIPID IS A FAT (SOLID AT ROOM TEMPERATURE) OR AN OIL (LIQUID AT ROOM TEMPERATURE). FATS, TYPICALLY FROM ANIMAL SOURCES, HAVE SATURATED FATTY ACIDS WITH NO DOUBLE BONDS BETWEEN CARBON ATOMS, LEADING TO TIGHTLY PACKED MOLECULES. OILS, OFTEN FROM PLANT SOURCES, CONTAIN UNSATURATED FATTY

ACIDS WITH ONE OR MORE DOUBLE BONDS, CAUSING KINKS IN THE HYDROCARBON CHAINS AND PREVENTING CLOSE PACKING. THESE MOLECULES ARE AN INCREDIBLY EFFICIENT FORM OF LONG-TERM ENERGY STORAGE, PROVIDING MORE THAN TWICE THE ENERGY PER GRAM COMPARED TO CARBOHYDRATES.

PHOSPHOLIPIDS: THE STRUCTURAL BASIS OF MEMBRANES

PHOSPHOLIPIDS ARE A MAJOR COMPONENT OF ALL CELL MEMBRANES. THEY ARE SIMILAR IN STRUCTURE TO TRIGLYCERIDES BUT HAVE A PHOSPHATE GROUP ATTACHED TO ONE OF THE CARBONS OF THE GLYCEROL BACKBONE, IN PLACE OF A THIRD FATTY ACID. THIS PHOSPHATE GROUP IS NEGATIVELY CHARGED AND HYDROPHILIC (WATER-ATTRACTING), WHILE THE TWO FATTY ACID TAILS ARE HYDROPHOBIC. THIS AMPHIPATHIC NATURE, POSSESSING BOTH HYDROPHILIC AND HYDROPHOBIC REGIONS, CAUSES PHOSPHOLIPIDS TO SPONTANEOUSLY ARRANGE INTO A BILAYER IN AN AQUEOUS ENVIRONMENT, WITH THE HYDROPHILIC HEADS FACING OUTWARD AND THE HYDROPHOBIC TAILS FACING INWARD. THIS ARRANGEMENT FORMS THE FUNDAMENTAL STRUCTURE OF ALL BIOLOGICAL MEMBRANES, ACTING AS A BARRIER BETWEEN THE CELL AND ITS SURROUNDINGS.

STEROIDS: SIGNALING MOLECULES AND STRUCTURAL COMPONENTS

STEROIDS ARE LIPIDS CHARACTERIZED BY A CARBON SKELETON CONSISTING OF FOUR FUSED RINGS. WHILE THEY DO NOT RESEMBLE OTHER LIPIDS IN THEIR GENERAL STRUCTURE, THEY ARE GROUPED WITH LIPIDS DUE TO THEIR HYDROPHOBIC PROPERTIES. CHOLESTEROL IS A KEY STEROID IN ANIMAL CELL MEMBRANES, AFFECTING FLUIDITY. STEROIDS ALSO INCLUDE HORMONES, SUCH AS TESTOSTERONE AND ESTROGEN, WHICH ACT AS CHEMICAL MESSENGERS REGULATING VARIOUS PHYSIOLOGICAL PROCESSES. THE CHARACTERISTIC FOUR-RING STRUCTURE IS THE DEFINING FEATURE OF THIS IMPORTANT CLASS OF BIOMOLECULES, WHICH ARE INVOLVED IN DIVERSE BIOLOGICAL FUNCTIONS FROM CELL STRUCTURE TO COMPLEX HORMONAL SIGNALING.

PROTEINS: THE WORKHORSES OF THE CELL

PROTEINS ARE ARGUABLY THE MOST VERSATILE AND ABUNDANT CLASS OF BIOMOLECULES, PERFORMING A STAGGERING ARRAY OF FUNCTIONS WITHIN LIVING ORGANISMS. THEY ARE INVOLVED IN EVERYTHING FROM CATALYZING BIOCHEMICAL REACTIONS (ENZYMES) AND PROVIDING STRUCTURAL SUPPORT TO TRANSPORTING MOLECULES, DEFENDING AGAINST PATHOGENS, AND TRANSMITTING SIGNALS. PROTEINS ARE POLYMERS MADE UP OF AMINO ACID MONOMERS, AND THEIR SPECIFIC SEQUENCE OF AMINO ACIDS DICTATES THEIR UNIQUE THREE-DIMENSIONAL STRUCTURE, WHICH IN TURN DETERMINES THEIR FUNCTION. THE COMPLEXITY AND DIVERSITY OF PROTEIN FUNCTIONS HIGHLIGHT THEIR CENTRAL ROLE IN CELLULAR AND ORGANISMAL LIFE.

AMINO ACIDS: THE BUILDING BLOCKS OF PROTEINS

THERE ARE 20 DIFFERENT TYPES OF AMINO ACIDS, EACH WITH A CENTRAL ALPHA CARBON ATOM BONDED TO FOUR GROUPS: AN AMINO GROUP ($-\text{NH}_2$), A CARBOXYL GROUP ($-\text{COOH}$), A HYDROGEN ATOM, AND A VARIABLE SIDE CHAIN, KNOWN AS THE R GROUP. THE R GROUP IS WHAT DISTINGUISHES ONE AMINO ACID FROM ANOTHER AND DETERMINES ITS CHEMICAL PROPERTIES, SUCH AS WHETHER IT IS POLAR, NONPOLAR, ACIDIC, OR BASIC. AMINO ACIDS ARE LINKED TOGETHER BY PEPTIDE BONDS, FORMED THROUGH DEHYDRATION REACTIONS, TO CREATE POLYPEPTIDE CHAINS. A POLYPEPTIDE CHAIN IS A POLYMER OF AMINO ACIDS.

THE LEVELS OF PROTEIN STRUCTURE

THE FUNCTION OF A PROTEIN IS INTRICATELY LINKED TO ITS PRECISE THREE-DIMENSIONAL SHAPE, WHICH IS ACHIEVED THROUGH A HIERARCHY OF STRUCTURAL LEVELS. THE PRIMARY STRUCTURE IS THE LINEAR SEQUENCE OF AMINO ACIDS IN THE POLYPEPTIDE CHAIN, DETERMINED BY THE GENETIC CODE. THE SECONDARY STRUCTURE REFERS TO THE LOCAL FOLDING OF THE POLYPEPTIDE CHAIN INTO REGULAR STRUCTURES, SUCH AS ALPHA-HELICES AND BETA-PLEATED SHEETS, STABILIZED BY HYDROGEN BONDS

BETWEEN BACKBONE ATOMS. THE TERTIARY STRUCTURE IS THE OVERALL THREE-DIMENSIONAL SHAPE OF A SINGLE POLYPEPTIDE CHAIN, RESULTING FROM INTERACTIONS BETWEEN THE R GROUPS OF AMINO ACIDS, INCLUDING HYDROGEN BONDS, IONIC BONDS, HYDROPHOBIC INTERACTIONS, AND DISULFIDE BRIDGES. FINALLY, THE QUATERNARY STRUCTURE EXISTS ONLY IN PROTEINS COMPOSED OF MORE THAN ONE POLYPEPTIDE SUBUNIT, DESCRIBING THE ARRANGEMENT OF THESE SUBUNITS RELATIVE TO EACH OTHER.

PROTEIN FUNCTION AND DENATURATION

THE SPECIFIC THREE-DIMENSIONAL STRUCTURE OF A PROTEIN ALLOWS IT TO PERFORM ITS DESIGNATED FUNCTION. FOR EXAMPLE, AN ENZYME'S ACTIVE SITE IS PRECISELY SHAPED TO BIND TO ITS SUBSTRATE. HOWEVER, PROTEINS ARE SENSITIVE TO THEIR ENVIRONMENT, AND CHANGES IN pH, TEMPERATURE, OR IONIC CONCENTRATION CAN DISRUPT THE WEAK INTERACTIONS THAT MAINTAIN THEIR STRUCTURE. THIS LOSS OF A PROTEIN'S NATIVE CONFORMATION AND THUS ITS BIOLOGICAL ACTIVITY IS CALLED DENATURATION. DENATURED PROTEINS ARE TYPICALLY NON-FUNCTIONAL, AND THE PROCESS CAN BE IRREVERSIBLE IF THE DENATURING CONDITIONS ARE SEVERE.

NUCLEIC ACIDS: INFORMATION CARRIERS

NUCLEIC ACIDS ARE THE MOLECULES RESPONSIBLE FOR STORING AND TRANSMITTING GENETIC INFORMATION. THE TWO MAJOR TYPES OF NUCLEIC ACIDS ARE DEOXYRIBONUCLEIC ACID (DNA) AND RIBONUCLEIC ACID (RNA). THESE POLYMERS ARE COMPOSED OF NUCLEOTIDE MONOMERS, AND THEIR SEQUENCES ENCODE THE INSTRUCTIONS FOR BUILDING AND OPERATING ALL LIVING ORGANISMS. THE DISCOVERY AND UNDERSTANDING OF NUCLEIC ACIDS HAVE REVOLUTIONIZED BIOLOGY, LEADING TO ADVANCEMENTS IN GENETICS, MOLECULAR BIOLOGY, AND MEDICINE.

DNA AND RNA: STRUCTURE AND FUNCTION

DNA IS A DOUBLE-STRANDED HELIX, WHERE TWO POLYNUCLEOTIDE STRANDS ARE HELD TOGETHER BY HYDROGEN BONDS BETWEEN COMPLEMENTARY BASE PAIRS (ADENINE WITH THYMINE, AND GUANINE WITH CYTOSINE). DNA IS THE PRIMARY MOLECULE OF HEREDITY, CARRYING THE GENETIC BLUEPRINT IN THE NUCLEUS OF EUKARYOTIC CELLS. RNA, ON THE OTHER HAND, IS TYPICALLY SINGLE-STRANDED AND PLAYS VARIOUS ROLES IN GENE EXPRESSION, INCLUDING MESSENGER RNA (mRNA), WHICH CARRIES GENETIC INFORMATION FROM DNA TO RIBOSOMES FOR PROTEIN SYNTHESIS; TRANSFER RNA (tRNA), WHICH BRINGS AMINO ACIDS TO THE RIBOSOME; AND RIBOSOMAL RNA (rRNA), A COMPONENT OF RIBOSOMES. RNA USES URACIL (U) INSTEAD OF THYMINE (T) AS A BASE.

THE ROLE OF NUCLEOTIDES

NUCLEOTIDES ARE THE MONOMERS OF NUCLEIC ACIDS. EACH NUCLEOTIDE CONSISTS OF THREE COMPONENTS: A NITROGENOUS BASE (ADENINE, GUANINE, CYTOSINE, THYMINE, OR URACIL), A FIVE-CARBON SUGAR (DEOXYRIBOSE IN DNA, RIBOSE IN RNA), AND ONE OR MORE PHOSPHATE GROUPS. THE PHOSPHATE GROUPS LINK THE SUGAR OF ONE NUCLEOTIDE TO THE SUGAR OF THE NEXT, FORMING THE SUGAR-PHOSPHATE BACKBONE OF THE NUCLEIC ACID STRAND. THE SEQUENCE OF NITROGENOUS BASES ALONG THIS BACKBONE CONSTITUTES THE GENETIC CODE, DETERMINING THE ORDER OF AMINO ACIDS IN PROTEINS AND THUS THE CHARACTERISTICS OF AN ORGANISM.

FAQ

Q: WHAT ARE THE FOUR MAIN CLASSES OF BIOMOLECULES DISCUSSED IN CAMPBELL BIOLOGY'S CHAPTER ON BIOMOLECULES?

A: THE FOUR MAIN CLASSES OF BIOMOLECULES ARE CARBOHYDRATES, LIPIDS, PROTEINS, AND NUCLEIC ACIDS.

Q: WHAT IS THE PRIMARY FUNCTION OF CARBOHYDRATES IN LIVING ORGANISMS?

A: CARBOHYDRATES PRIMARILY SERVE AS A SOURCE OF ENERGY FOR CELLULAR PROCESSES AND ALSO PLAY ROLES IN STRUCTURAL SUPPORT AND CELL RECOGNITION.

Q: HOW DO FATS AND OILS DIFFER, AND WHAT IS THEIR MAIN ROLE?

A: FATS ARE TYPICALLY SOLID AT ROOM TEMPERATURE AND COME FROM ANIMAL SOURCES, WHILE OILS ARE LIQUID AND OFTEN FROM PLANT SOURCES. THEIR MAIN ROLE IS LONG-TERM ENERGY STORAGE AND INSULATION. THE DIFFERENCE LIES IN THE SATURATION OF THEIR FATTY ACID CHAINS; FATS HAVE SATURATED FATTY ACIDS, WHILE OILS HAVE UNSATURATED ONES.

Q: WHAT MAKES PHOSPHOLIPIDS IMPORTANT FOR CELL MEMBRANES?

A: PHOSPHOLIPIDS ARE AMPHIPATHIC, HAVING BOTH HYDROPHILIC (WATER-ATTRACTING) HEADS AND HYDROPHOBIC (WATER-REPELLING) TAILS. THIS PROPERTY ALLOWS THEM TO FORM THE BILAYER STRUCTURE THAT IS THE FUNDAMENTAL BASIS OF ALL BIOLOGICAL MEMBRANES, ACTING AS A BARRIER.

Q: WHAT ARE THE BUILDING BLOCKS OF PROTEINS, AND HOW DOES THEIR SEQUENCE DETERMINE FUNCTION?

A: THE BUILDING BLOCKS OF PROTEINS ARE AMINO ACIDS. THERE ARE 20 DIFFERENT TYPES OF AMINO ACIDS, AND THEIR SPECIFIC LINEAR SEQUENCE IN A POLYPEPTIDE CHAIN (PRIMARY STRUCTURE) DICTATES THE PROTEIN'S FOLDING INTO A COMPLEX THREE-DIMENSIONAL SHAPE, WHICH IS ESSENTIAL FOR ITS SPECIFIC FUNCTION.

Q: WHAT IS DENATURATION, AND WHAT CAUSES IT?

A: DENATURATION IS THE LOSS OF A PROTEIN'S NATIVE THREE-DIMENSIONAL STRUCTURE, LEADING TO A LOSS OF ITS BIOLOGICAL FUNCTION. IT CAN BE CAUSED BY CHANGES IN TEMPERATURE, pH, OR IONIC CONCENTRATION THAT DISRUPT THE WEAK CHEMICAL BONDS HOLDING THE PROTEIN'S STRUCTURE TOGETHER.

Q: WHAT ARE THE TWO MAIN TYPES OF NUCLEIC ACIDS, AND WHAT IS THEIR SHARED FUNDAMENTAL ROLE?

A: THE TWO MAIN TYPES OF NUCLEIC ACIDS ARE DNA (DEOXYRIBONUCLEIC ACID) AND RNA (RIBONUCLEIC ACID). THEIR SHARED FUNDAMENTAL ROLE IS TO STORE AND TRANSMIT GENETIC INFORMATION.

Q: WHAT ARE THE THREE COMPONENTS OF A NUCLEOTIDE?

A: A NUCLEOTIDE IS COMPOSED OF A NITROGENOUS BASE, A FIVE-CARBON SUGAR (DEOXYRIBOSE IN DNA, RIBOSE IN RNA), AND ONE OR MORE PHOSPHATE GROUPS.

Q: WHY ARE LIPIDS CONSIDERED HYDROPHOBIC?

A: LIPIDS ARE CONSIDERED HYDROPHOBIC BECAUSE THEY ARE PREDOMINANTLY COMPOSED OF NONPOLAR HYDROCARBON CHAINS,

WHICH DO NOT READILY INTERACT WITH WATER MOLECULES.

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