RADIOACTIVE ELEMENTS I. Nuclear structure: The basic idea of nuclear structure, that the nucleus of an atom is composed of protons and neutrons, collectively called nucleons , with the exception of 1H 1 . ● X is the symbol for the element, ● A is the mass number A = Z+N ● Z is the atomic number = Number of protons = Number of electrons ● N is the number of neutrons II. Isotopes, Isobars and Isotones: III. Nuclear Equation: Nuclear reactions follow conservation laws, and they are balanced in two ways: 1. The sum of the mass numbers of the reactants equals the sum of the mass numbers of the products. 7N 14 + 2He 4 ￼ 8O 17 + 1H 1 2. The sum of the charges of the reactants equals the sum of the charges of the products. Dr A. SADOUKI Physics/L1 2/10 IV. Radioactive Elements: IV.1. Radioactive Decay: The spontaneous change of an unstable nuclide into another is radioactive decay. The unstable nuclide is called the parent nuclide; The nuclide that results from the decay is known as the daughter nuclide. The daughter nuclide may be stable, or it may decay itself. The radiation produced during radioactive decay is such that the daughter nuclide lies closer to the band of stability than the parent nuclide. IV.2. Band of stability: Dr A. SADOUKI Physics/L1 3/10 For all existing nuclides, if we plot the number of neutrons N=A-Z as a function of the number of protons Z on a diagram, we obtain a distribution following a line of stability that deviates slightly from the first bisector. All nuclides placed on the same vertical line are isotopes (same Z). All nuclides placed on the same horizontal line are isotones (same N). All nuclides placed on the same perpendicular to the first bisector are isobars (same A). Unstable nuclides with an excess of neutrons are located above the line of stability; they move closer to it through an internal nuclear reaction that transforms a neutron into a proton, following the scheme: Unstable nuclides with an excess of protons are located below the line of stability; they approach it through an internal nuclear reaction that changes a proton into a neutron, according to the process: The heaviest elements, situated at the end of the line of stability, have insufficient internal energy to ensure the cohesion of all nucleons. This marks the region of spontaneous fission and α-radioactivity. The positive electron released by the nucleus corresponds to ￼+ radioactivity and is accompanied by the emission of a neutrino. The negative electron emitted by the nucleus corresponds to ￼- radioactivity and is accompanied by the emission of an antineutrino. IV.3. Types of radioactive decay: a. Alpha Decay The nucleus emits an alpha particle (2 protons, 2 neutrons). Reduces atomic number by 2 and mass number by 4. b. Beta Decay : ￼ Negaton Decay : A neutron turns into a proton, emitting an electron and an antineutrino. Increases atomic number by 1. ￼ Positron Decay : A proton turns into a neutron, emitting a positron and a neutrino. Dr A. SADOUKI Physics/L1 4/10 Decreases atomic number by 1. c. Gamma Emission : The nucleus releases excess energy as gamma radiation (high-energy photons). No change in atomic number or mass. d. Electron Capture: The nucleus absorbs an inner electron, turning a proton into a neutron. Decreases atomic number by 1. e. Spontaneous Fission: IV.4. Penetrating Power & Harmful Effects: Dr A. SADOUKI Physics/L1 5/10 Penetrating Power Harmful Effects Alpha (α) Low penetrating power. Can be stopped by a sheet of paper or a few centimeters of air. Cannot penetrate human skin. High ionizing power but only harmful if ingested or inhaled (e.g., via contaminated food or air). Most harmful internal hazard Cannot damage tissues externally due to its low penetration. Beta (￼) Moderate penetrating power. Can pass through paper but is stopped by a few millimeters of aluminum or plastic. Can penetrate skin but not deeper tissues. Moderate ionizing power. Can cause skin burns and internal damage if ingested or inhaled. More harmful than alpha radiation for external exposure. Gamma (□) High penetrating power. Can pass through several centimeters of lead or meters of concrete. Requires dense materials for significant shielding. Low ionizing power but highly penetrating. Can cause severe internal and external damage to tissues. Most harmful external hazard IV.5. Induced Nuclear Reactions: Converting a stable nucleus to another more massive nucleus by bombarding it with subatomic particles in a nuclear transmutation reaction (carry out the reverse reaction). V. Kinetics of radioactive decay: The chemical reaction of nuclear decay follows first-order kinetics. Decay rate = – dN dt = □ N ln □N□0 □N□ = □t N = N0e –□ t □ : radioactive decay constant, and a characteristic value for each radioactive isotope. which has units of inverse time (s–1 , mn–1 , h–1 , yr–1 ) V.1. Constant half life (t1/2): Each radioactive nuclide has a characteristic, constant half-life (t1/2), the time required for half of the atoms in a sample to decay. Thus the half-life of a reaction is the time required for the reactant concentration to decrease from [N]0 to [N]0/2. 2α 4 + 7N 14 □ 8O 17 + 1P 1 …….. (01) Dr A. SADOUKI Physics/L1 6/10 The half-life of a first-order reaction is independent of the concentration of the reactants. Substituting [N]0/2 for [N] and t1/2 for t (to indicate a half-life ) into Equation (01) gives: ln □N□0 □N□0/2 = □ t1/2 = ln2 t1/2 = ln2 □ / V.2. Number of radioactive half-lives (n): V.3. Activity: In any sample of a given radioactive substance, the number of atoms of the radioactive isotope must decrease with time as their nuclei decay to a more stable isotope nuclei. n = t t1/2 …….. (02) Dr A. SADOUKI Physics/L1 7/10 Using N to represent the number of atoms of the radioactive isotope, we can define the rate of decay of the sample, which is also called its activity (A) as the decrease in the number of the radioisotope's nuclei per unit time: A = – ΔN Δt …….. (04) The activity of a sample is directly proportional to the number of atoms (N) of the radioactive isotope in the sample: A = □ N …….. (05) □ : radioactive decay constant. If we combine Equation (04) and Equation (05), we obtain the relationship between the number of decays per unit time and the number of atoms of the isotope in a sample: – ΔN Δt = □ N – ΔN Δt :number of decays per unit time. N :number of atoms of the isotope in a sample. □ Radioactive Decay Rate is: Constant, Independent of temperature, Independent of the chemical or physical environment □ Units of Activity: Becquerel (Bq) This is the International System (SI) unit used to measure the activity of a radioactive source. 1 Bq corresponds to 1 disintegration per second. Curie (Ci) (former unit) …….. (06) Dr A. SADOUKI Physics/L1 8/10 This unit is often used in nuclear and medical industries. 1 Curie corresponds to 3.7 × 1010 disintegrations per second. V.4. Specific Activity: The specific activity of an element is the activity per unit mass Asp = A m Ci/kg This specific activity of an element can be expressed per unit volume or mole, provided the solution is homogeneous: Asp = A V Ci/ml Asp = A n Ci/mol V.5. Relation between the radioelement's masse & its Activity: □: radioactive constant expressed in s–1 M: molar mass of the radioelement expressed in g m: mass of radioelement in g. V.6. Effective, Biological and Physical Half-lives: When a radioelement is introduced into the body, its concentration in the blood varies over time, not only because of its radioactive (physical) decay, but also because of its biological uptake and elimination. The variation in radioelement activity resulting from these 2 phenomena is expressed as a function of time according to: Dr A. SADOUKI Physics/L1 9/10 VI. Applications: VI.1. Radiometric Dating using carbon-14: This method is accurate for dating carbon-containing substances that are up to about 30,000 years old, and can provide reasonably accurate dates up to a maximum of about 50,000 years old. The carbon-14 isotope, created continuously in the upper regions of Earth's atmosphere, reacts with atmospheric oxygen or ozone to form 14CO2. As a result, the CO2 that plants use as a carbon source for synthesizing organic compounds always includes a certain proportion of 14CO2 molecules as well as nonradioactive 12CO2 and 13CO2. Any animal that eats a plant ingests a mixture of organic compounds that contains approximately the same proportions of carbon isotopes as those in the atmosphere. When the animal or plant dies, the carbon-14 nuclei in its tissues decay to nitrogen-14 nuclei by a radioactive process known as beta decay, which releases low-energy electrons (? particles) that can be detected and measured: The 14C/12C ratio in living organisms is 1.3 × 10-12, with a decay rate of 15 dpm/g of carbon. Comparing the disintegrations per minute per gram of carbon from an archaeological sample with those from a recently living sample enables scientists to estimate the age of the artifact VI.2. Isotopic Dilution: Quantitative analytical technique where a known amount of an isotopically enriched substance (the tracer) is added to a sample. This method is used to determine the concentration or amount of an element or compound in a mixture by measuring the isotopic ratio before and after the addition of the tracer. Used in chemistry, biology, and geology to measure element concentrations. Principle: Dr A. SADOUKI Physics/L1 10/10 Introduce a known quantity (a*) of a radioactive tracer identical to the sample to be measured (x). Thoroughly homogenize the mixture. Extract a quantity (b) containing both a proportion of the tracer and the sample to be measured (x+a*). The principle of this assay assumes that the activity (A1) introduced from (a) is recovered after mixing with the sample to be measured (x) as the combined activity (A2). Neglecting the radioactive decay time, we have: However, when the duration of the manipulation is significant compared to the half-life of the radioactive element. In this case, we have: A1 ≠ A2 A1 ′ is the activity corrected for the decay occurring .during the experimental time. t: time of the experiment. t1/2: half-life of the radioactive element