CHAPTER 4

AGES OF DERGAON METEORITE

4.1 INTRODUCTION

Meteorite offered a good chance to look backward in time. Numerous methods have been tried to determine the age of the meteorite. However, in case of age of meteorite, a generalization is not possible. Different method involving different elements and different assumption, usually give different age. Actually each method gives a point on the time scale to a specific event in the history of the matter making the meteorite sample. These events are defined by the particular age equation of the method and by chemical and physical properties of the parent and daughter elements on which the method is based. Thus events such as nucleosynthesis, general chemical separation processes, the formation of the minerals in the sample, subsequent heating, the breakup of the possible parent body and the time of fall of the meteorite, may each be recorded by specific nuclear processes. The earliest work on the age of the meteorite was determined by Paneth and his co-worker in 1942. They determined the helium content of a number of iron meteorites, and on the assumption that this helium was produced by radioactive disintegration of uranium and thorium, obtained the age ranging from \( (10^6 \text{ to } 7 \times 10^9) \) years. Since the latter figure greatly exceeded the age of the solar system as conceived at that time, the interpretation of these result was the subject of much controversy. As determination of age of the meteorite is important in the study of meteorite, hence modified calculation for age determination was carried out later by different scientist. They mainly divide age in meteorite in different categories.

a. Cosmic Ray Exposure Age (CRE) and Terrestrial ages.
b. Gas retention age
c. Formation and metamorphic ages
A. Cosmic ray exposure age and Terrestrial age

The mean absorption depth of primary cosmic rays in meteorite matter is of the order of 1m. Therefore, the inner parts of a parent body will be shielded from spallation reactions until the body breaks up. After a meteorite leaves its parent body and before it become shielded by Earth’s atmosphere it exposed to cosmic ray chiefly protons with mean energy of about a billion electron volts that interact with the elements that comprises it to form cosmogenic nuclides (e.g. $^3\text{He}$, $^{21}\text{Ne}$, $^{38}\text{Ar}$ and $^{54}\text{Mn}$). Therefore it is possible to determine the age of break-up from the study of stable and unstable cosmogenic nuclides in meteorites but this requires the assumption that the cosmic flux was constant with time. However meteorites that came from the surface of the parent body will give anomalous break-up dates. There are other distinct differences in the cosmic ray exposure of irons and stones. Some meteorite groups show clustering in their exposure ages. This reflects different major phases of disruption in the source region of meteorites. Because the production of cosomgenic nuclide falls off with the depth in a body, it is also possible to determine the approximate pre-atmospheric size of a meteorite from the distribution pattern of cosmogenic nuclides within it.

B. Gas Retention age

At temperature higher than 200 to 300ºC any gas that may have been produced within a meteorite by the decay of a radioactive nuclide (e.g. $^{40}\text{Ar}$ from $^{40}\text{K}$) may diffuse through the meteorite and be lost. The measurement of the concentration of such daughter and parent isotopes will give the date at which loss of gaseous nuclide ceased. If a meteorite had not suffered a heating event after it first solidified then its ‘gas retention age’ will be same as its ‘formation age’. As noble gases results from decay of certain long lived radionuclide

$^{40}\text{K} \rightarrow ^{40}\text{Ar}$

$^{238}\text{U} \rightarrow ^{206}\text{Pb} + ^{4}\text{He}$
$^{235}\text{U}\rightarrow ^{207}\text{Pb} + 7^4\text{He}$

$^{232}\text{Th}\rightarrow ^{208}\text{Pb} + 6^4\text{He}$

These noble gases only remain in situ at low temperatures, being able to move through mineral lattices at raised temperature. Thus they can thus be used to date the last heating of meteorite material (other than ablation heating). The age obtained should represent either the date of termination of the cooling of the parent body or any subsequent heating of the material after separation from it, while orbiting in space prior to the arrival of the earth.

C. Formation and metamorphic age.

The measurement of the proportions of daughter and parent isotope also allows the age of formation of meteorite to be calculated. In solar nebula extensive melting believed to have occurred within the parent body sometime after its formation by cold accretion from the dust of solar nebula (the accretion model). The melting of the parent bodies cannot solely due to radiogenic processes, but also due to gravitational inwards of the last accreted heavy metallic fraction as suggested by Ringwood. Hence the ‘age’ that is determined is the time at which the process of chemical fractionation of relevant isotopes in different phases of the cooling meteorite ceased.

For measurement of formation age isotope of Rb and Sr have been most widely used. Sm–Nd and Lu-Hf parameter are also used for determination of formation age.

Here in case of Dergaon meteorite a study regarding CRE age is made on section 4.3 and Gas retention age on section 4.4. However terrestrial age is not discussed here as Dergaon meteorite is collected soon after its fall. Also formation or metamorphic age is not discussed for unavailability of required data. Noble gas isotopic ratio and concentration give useful information about the history of the meteorite i.e. formation processes and thermal event occurred on their parent body as well as cosmic ray effect in space. Hence in section 4.2
noble gases in Dergaon meteorite is discussed. In section 4.5 discussion and conclusion are made.

4.2 Noble gases in Dergaon Meteorite

The noble gas data based on stepwise pyrolysis of fragment from largest recovered piece of Dergaon meteorite (Shukla et al, 2005) are given in table 1a and 1b. The data are corrected for blanks, interferences and instrumental mass discrimination. Blanks at all temperature are <5% for all gases and have near atmospheric composition within the limit of uncertain tare. The errors in the abundances are ±10% (for He, Ar and Kr) and ±15% (for Kr and Xe). Errors in isotopic compositions represents 95% of confidence limit. It is expected that the noble gases released from the sample would be a mixture of components of different origins, such as in cosmogenic or radiogenic or radiogenic components with chronological information and trapped (possibly primordial) components. Hence an attempt is made here to such components and possibly estimates their relative contributions. In the following discussion by considering Eugster formulation it is considered by using end member isotopic ratios as

$\text{^3He}/^4\text{He})_c=0.2$

$\text{^20Ne}/^22\text{Ne})_c =0.80$

$\text{^38Ar}/^36\text{Ar})_c(\text{^38Ar}/^36\text{Ar})_t=0.188$

Where suffixes “c” and “t” means cosmogenic and trapped components respectively.
Table 1a: He, Ne and Ar in the Dergaon meteorite (10^{-8} cm^3 STP/g)

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>$^4$He</th>
<th>$^{22}$Ne</th>
<th>$^{36}$Ar</th>
<th>$^3$He/$^4$He (10^{-4})</th>
<th>$^{20}$Ne/$^{22}$Ne</th>
<th>$^{38}$Ar/$^{36}$Ar</th>
<th>$^{40}$Ar/$^{36}$Ar</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>34.3</td>
<td>0.044</td>
<td>0.01</td>
<td>37.5</td>
<td>0.9614</td>
<td>0.866</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>±3.2</td>
<td>±0.0846</td>
<td>±.0110</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>1597</td>
<td>1.444</td>
<td>0.137</td>
<td>52.6</td>
<td>0.9721</td>
<td>0.8281</td>
<td>0.9626</td>
</tr>
<tr>
<td></td>
<td>±4.4</td>
<td>±0.0009</td>
<td>±.0020</td>
<td></td>
<td></td>
<td>±.0028</td>
<td>±178</td>
</tr>
<tr>
<td>1600</td>
<td>142.8</td>
<td>1.590</td>
<td>1.146</td>
<td>103.0</td>
<td>0.9698</td>
<td>0.8627</td>
<td>0.3914</td>
</tr>
<tr>
<td></td>
<td>±8.7</td>
<td>±0.0011</td>
<td>±.0012</td>
<td></td>
<td></td>
<td>±.0001</td>
<td>±30</td>
</tr>
<tr>
<td>Total</td>
<td>1774</td>
<td>3.038</td>
<td>1.283</td>
<td>56.4</td>
<td>0.9709</td>
<td>0.8462</td>
<td>0.4528</td>
</tr>
<tr>
<td></td>
<td>±4.8</td>
<td>±0.0012</td>
<td>±.0016</td>
<td></td>
<td></td>
<td>±.0004</td>
<td>±46</td>
</tr>
</tbody>
</table>

Table 1b: Kr and Xe in the Dergaon meteorite (in 10^{-12} cc STP/g) [$^{84}$Kr=100, $^{132}$Xe=100]

<table>
<thead>
<tr>
<th>$^{84}$Kr</th>
<th>$^{132}$Xe</th>
<th>$^{84}$Kr</th>
<th>$^{83}$Kr</th>
<th>$^{86}$Kr</th>
<th>$^{130}$Xe</th>
<th>$^{131}$Xe</th>
<th>$^{124}$Xe</th>
<th>$^{136}$Xe</th>
</tr>
</thead>
<tbody>
<tr>
<td>126.9</td>
<td>265.9</td>
<td>21.46</td>
<td>142.9</td>
<td>16.48</td>
<td>82.33</td>
<td>37.85</td>
<td>31.84</td>
<td></td>
</tr>
<tr>
<td>± .03</td>
<td>± .08</td>
<td>± .3</td>
<td>±.06</td>
<td>±.24</td>
<td>±.08</td>
<td>±.10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Lighter noble gas (He, Ne)**

Isotopic composition of helium observed at temperature 400°C and 1600°C show wide variations. While Neon show small variations. Observed \(^{20}\text{Ne}/^{21}\text{Ne}\) and \(^{21}\text{Ne}/^{22}\text{Ne}\) ratios agree with each other within 2σ uncertainty levels. The weighted means of \(^{20}\text{Ne}/^{22}\text{Ne}\) and \(^{21}\text{Ne}/^{22}\text{Ne}\) ratios are 0.9709±.0012 and 0.8462±.0016 respectively, which is consistent with the range of ratio reported for cosmogenic components from chondrite (Jisun Park et al, 2003; Mitsumato et al, 2002).

Helium also released at temperature between 400°C and 1600°C and relatively constant \(^3\text{He}/^4\text{He}\). The observed \(^3\text{He}/^4\text{He}\) ratio is between 0.0038-0.0056. Unlike observed neon composition at those temperature, the value \(^3\text{He}/^4\text{He}\) are lower than typical cosmogenic value 0.2. Thus it is reasonable to extract helium as a mixture of cosmogenic and radiogenic components and that trapped helium is negligible in Dergaon meteorite.

**Heavier noble gas (Ar, Kr and Xe)**

The measured \(^{38}\text{Ar}/^{36}\text{Ar}\) and \(^{40}\text{Ar}/^{36}\text{Ar}\) ratio vary from 0.391 to 0.963 and 30 to 9229 respectively. These variations most likely are explainable with mixing of cosmogenic, radiogenic and trapped argon components. It is possible to estimate the amount of these components by assuming appropriate and member isotopic compositions. It can be assumed that the measured \(^{38}\text{Ar}/^{36}\text{Ar}\) ratio results from binary mixing between trapped \([(^{38}\text{Ar}/^{36}\text{Ar})t=0.188]\) and cosmogenic components \([(^{38}\text{Ar}/^{36}\text{Ar})c=1.5]\). The \(^{40}\text{Ar}\) above 900°C can be considered as radiogenic component. However there is an obvious contribution of atmospheric argon between 600°C and 800°C fractions. The heavier noble gases \(^{84}\text{Kr}\) and \(^{132}\text{Xe}\) are mostly of trapped origin and terrestrial atmospheric contamination is not very significant.
Table 2: Cosmogenic, radiogenic and trapped noble gas components ($10^{-8}$ cc STP/g)

<table>
<thead>
<tr>
<th>Cosmogenic</th>
<th>Radiogenic</th>
<th>Trapped</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^3$He</td>
<td>$^4$He</td>
<td>$^{36}$Ar</td>
</tr>
<tr>
<td>126.9</td>
<td>1722</td>
<td>1.02</td>
</tr>
<tr>
<td>$^{21}$Ne</td>
<td>$^{40}$Ar</td>
<td>$^{84}$Kr</td>
</tr>
<tr>
<td>2.56</td>
<td>3043</td>
<td>0.0126</td>
</tr>
<tr>
<td>$^{38}$Ar</td>
<td>$^{132}$Xe</td>
<td>0.0265</td>
</tr>
<tr>
<td>0.388</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.3 Cosmic ray exposure ages

The interactions of cosmic ray particles with extraterrestrial materials produce a cascade of secondary particles and variety of cosmogenic particles. These cosmogenic nuclides provide information regarding dating and tracing various events in the history of the investigated objects. In general from these nuclides information regarding the exposure ages, terrestrial ages, preatmospheric size and shielding condition of the sample can be extracted. However to extract information it is extremely important to know production rate as a function of depth in objects of various radii and chemical compositions. The isotope $^3$He, $^{21}$Ne and $^{38}$Ar and their ratios are often used to study cosmic ray exposure ages.

Here, above mention isotopes are used for determination of cosmic ray exposure ages of Dergaon meteorite. A variety of model exists for calculation of cosmogenic nuclide production rates in meteorite till to date [Bhandari et al, 1993; Graf et al, 1990; Honda, 1988; Leya et al, 2000; Masarik et al, 1992; Michael et al, 1991]. Here to calculate cosmic ray exposure age of Dergaon meteorite, approaches are made as follows.

To calculate cosmic ray exposure age, certain assumptions about the irradiation and history of meteorite are made. The assumptions are-

(i) the flux of primary cosmic rays are constant in time
(ii) the flux of primary cosmic rays are constant in space
(iii) the shape of the sample didn’t change appreciably

(iv) the chemical composition of the sample didn’t change appreciably

(v) the sample didn’t lose nuclides of interest except by known radioactive decay.

Hence cosmic ray exposure ages are determined by considering the abundances of cosmogenic nuclei produced by reactions between meteorite and galactic cosmic rays. This can be simply represented by the following equation

\[ T_S = \frac{C^S}{P^S} \rightarrow (1) \]

Where \( T_S \) is the exposure age, \( C^S \) is the concentration of stable cosmogenic nuclide [S can be \(^3\text{He}, ^{21}\text{Ne} \) and \(^{38}\text{Ar}\)] and \( P^S \) is the production rate.

To study Cosmic ray exposure ages, the concentration of noble gas is divided into cosmogenic(c), trapped(t) and radiogenic(r) component.

The production rates of cosmogenic nuclei are determined by the isotopic ratio between stable and radioactive nuclei couple [Anders, 1966]. However, production rates also changes for different size and shielding depths of the meteorite [Eugster, 1988]. Here in case of Dergaon meteorite \((^{22}\text{Ne}/^{21}\text{Ne})_c\) ratio is taken as most sensitive to shielding effect. This being considered using Eugster (1988) assumption.

Using \((^{22}\text{Ne}/^{21}\text{Ne})_c\) as shielding parameter or indicator, a good approximation regarding production rate of cosmogenic \(^3\text{He}, ^{21}\text{Ne} \) and \(^{38}\text{Ar}\) can be made. Based on data of 138 chondrites, Nishiizumi in 1980 reported a least square fit equation to calculate \((^{3}\text{He}/^{21}\text{Ne})_c\) as follows
\[(^{3}\text{He}/^{21}\text{Ne})_c = 21.77 (^{22}\text{Ne}/^{21}\text{Ne})_c - 19.32 \rightarrow (2)\]

However, above equation give a correct value for a range of (1.06-1.30) of \((^{22}\text{Ne}/^{21}\text{Ne})_c\).

To calculate the cosmic ray exposure for Dergaon meteorite we use depth sensitive \((^{22}\text{Ne}/^{21}\text{Ne})_c\) ratio as the shielding parameter and abundance of target elements, production rates of \(^3\text{He}, ^{21}\text{Ne}\) and \(^{38}\text{Ar}\) are calculated according to the following equation

\[P^3 = F_H [2.09 - 0.43 (^{22}\text{Ne}/^{21}\text{Ne})_c] \quad ; \quad F_H = 0.98 \rightarrow (3)\]
\[P^{21} = 1.61 F_H' [21.77 (^{22}\text{Ne}/^{21}\text{Ne})_c - 19.32]^{-1}; \quad F_H' = 0.93 \rightarrow (4)\]
\[P^{38} = F_{H''} [0.125 - 0.071 (^{22}\text{Ne}/^{21}\text{Ne})_c] \quad ; \quad F_{H''} = 1.08 \rightarrow (5)\]

Here \(P^3, P^{21}\) and \(P^{38}\) are production rates for \(^3\text{He}, ^{21}\text{Ne}\) and \(^{38}\text{Ar}\) respectively. The production rates are related to target composition and \(F_H, F_H'\) and \(F_{H''}\) are correction factor for H- Group chondrite. The shielding parameter \((^{22}\text{Ne}/^{21}\text{Ne})_c\) is corrected for \((^{3}\text{He}/^{21}\text{Ne})\). This is based on reactions of \(^{24}\text{Mg}(n,\alpha)^{21}\text{Ne}\) and \(^{25}\text{Mg}(n,\alpha)^{22}\text{Ne}\). The production of \(^{21}\text{Ne}\) increases with secondary neutron in flux, whereas \(^{22}\text{Ne}\) is insignificant. This is because relative abundance of \(^{25}\text{Mg}(\approx 10\%)\) is much less than \(^{24}\text{Mg}(\approx 79\%).\)

In case of Dergaon meteorite, \((^{22}\text{Ne}/^{21}\text{Ne})_c = 1.181 \pm 0.002\) and chemical composition of Dergaon meteorite, we have estimated production rates of cosmogenic \(^3\text{He}, ^{21}\text{Ne}\) and \(^{38}\text{Ar}\) (Eugster, 1988) using the set of equation (3), (4) and (5). Thereby, the cosmic ray exposure age of Dergaon meteorite is estimated. These results are summarized in table 1.
The calculated cosmic ray exposure ages using $^3\text{He}(T_3)$, $^{21}\text{Ne}(T_{21})$ and $^{38}\text{Ar}(T_{38})$ are 6.5 My, 10.9 My and 8.8 My respectively. In case $T_3$ it shows a short exposure age and $T_{38}$ also shows a nominal short age.

Table 3: Cosmogenic $^3\text{He}$, $^{21}\text{Ne}$ and $^{38}\text{Ar}$ concentration, production rates ($P_3$, $P_{21}$ and $P_{38}$) and cosmic ray exposure ages

<table>
<thead>
<tr>
<th>$^3\text{He}$</th>
<th>$^{21}\text{Ne}$</th>
<th>$^{38}\text{Ar}$</th>
<th>$^{22}\text{Ne}/^{21}\text{Ne}$</th>
<th>$P_3$</th>
<th>$P_{21}$</th>
<th>$P_{38}$</th>
<th>$T_3$</th>
<th>$T_{21}$</th>
<th>$T_{38}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10$^5$ c.c STP/g)</td>
<td>(10$^9$ cc STP/g/My)</td>
<td>(My)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>25.6</td>
<td>3.88</td>
<td>1.181</td>
<td>15.5</td>
<td>2.34</td>
<td>0.44</td>
<td>6.5</td>
<td>10.9</td>
<td>8.8</td>
</tr>
</tbody>
</table>

4.4 Gas Retention Ages of Dergaon meteorite

The gas retention ages can be estimated for radiogenic element found in the meteorite sample. In case of Dergaon meteorite radiogenic $^4\text{He}$ and $^{40}\text{Ar}$ are considered to calculate age. In general $^4\text{He}$ derived from $\alpha$-decay of $^{235}\text{U}$, $^{238}\text{U}$ and $^{232}\text{Th}$ and $^{40}\text{Ar}$ derived from electron capture decay of $^{40}\text{K}$. Earlier the interpretation of gas retention ages was made in detail by Goles et al in 1960. They assumed that there are three consecutive eras during which gas losses can occur-

1. the initial cooling of the parent bodies after cessation of melting and metamorphism
2. storage of the meteorite in the parent body at high enough temperature to permit gases to diffuse
3. Solar heating of the meteorite after its departure from the parent body.
4.4.1 Calculation by using radiogenic (K-Ar) isotope

The decay of $^{40}$K is a branching process. In the process, 10.48% of $^{40}$K decays to $^{40}$Ar by $\beta^-$ decay followed by gamma decay to ground state and by electron capture direct to ground state and 89.52% decays to $^{40}$Ca by $\beta^-$ decay to ground state. This is presented in fig.1 [McDougall and Harrison, 1999].

![Branching diagram showing the decay scheme for 40K, showing decay to 40Ar and 40Ca (after McDougall and Harrison, 1999)](image)

Here using ($^{40}$K→$^{40}$Ar) dating, the amount of radiogenically produced $^{40}$Ar in Dergaon meteorite is considered.

The equation for K-Ar isotope system considered is

$$ t = \frac{1}{\lambda} \ln \left[ 1 + \frac{\lambda}{\lambda_\gamma + \lambda'_{\gamma'}} \frac{^{40}\text{Ar}}{^{40}\text{K}} \right] \quad \rightarrow (6) $$

Here $\lambda$ is the total decay constant and ($\lambda_\gamma + \lambda'_{\gamma'}$) is partial decay constant. ($^{40}\text{Ar}/^{40}\text{K}$) is the ratio of radiogenic daughter product to the parent $^{40}$K [Begemann et al., 2001]. Since there is no natural fractionation of potassium isotope, the ratio is constant. The value of decay constants are taken from...
Steiger and Jaeger [1977] given in table 2. Thus by measuring the concentration of potassium and isotope ratio of Ar, we have calculated the gas retention age of the Dergaon meteorite, and found to be 1.5 Gy

Table 4: Decay constant for K-Ar after Steiger and Jaeger [1977]

<table>
<thead>
<tr>
<th>Decay</th>
<th>Decay factor</th>
<th>Value ($\text{y}^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{40}\text{K} \rightarrow ^{40}\text{Ca}$ [by $\beta^-$]</td>
<td>$\lambda_{\beta^-}$</td>
<td>4.962×10^{-10}</td>
</tr>
<tr>
<td>$^{40}\text{K} \rightarrow ^{40}\text{Ar}$</td>
<td>$\lambda_e$</td>
<td>0.572×10^{-10}</td>
</tr>
<tr>
<td>$^{40}\text{K} \rightarrow ^{40}\text{Ar}$ [by e capture]</td>
<td>$\lambda_e^-$</td>
<td>0.0088×10^{-10}</td>
</tr>
<tr>
<td>Combined value</td>
<td>$\lambda$</td>
<td>5.543×10^{-10}</td>
</tr>
</tbody>
</table>

$^{40}\text{K}/^{40}\text{K}=0.0001167$

4.4.2 (U, Th-He) gas Retention Age

To reassure the value, here we have tried to calculate gas retention age by using U-Th,He. To find the U, Th-He age it is very important to find out actual amount of radiogenic component of helium. Among the helium isotope $^4\text{He}$ found to be radiogenic. However there are probability of presence of “planetary type” $^4\text{He}$ that trapped during grain formation in solar nebula. Although the amount of trapped component is small compared to radiogenic $^4\text{He}$ produced by decay of uranium and thorium isotopes $^{235}\text{U}$, $^{238}\text{U}$ and $^{232}\text{Th}$. The radiogenic $^4\text{He}$ may not be pure and contaminates by $^3\text{He}$. In most of the chondritic studies correction factor is small. But still this value may be significant in case of low gas retention age.

The groups mean concentration of Th and U listed by Wasson and Kallemeyn (1988) are 42 ppb and 12 ppb in H–group chondrite respectively. The data used for these estimate were largely isotopic dilution data from studies carried out during the post two decades. In case of Dergaon meteorite we have
concentration of U and Th are 28 ppb (parts per billion) and 26 ppb respectively [ICP-MS studies]. Here we used $^{235}\text{U}$ and $^{238}\text{U}$ abundances for those isotopes are 99.2743% and 0.7200% respectively. The U, Th-He age can be obtained by considering the relation

$$^4\text{He} = 8[^{238}\text{U}](e^{\lambda_{238} t} - 1) + (7/137.88)[^{238}\text{U}](e^{\lambda_{235} t} - 1) + 6[^{232}\text{Th}(e^{\lambda_{232} t} - 1)] \rightarrow (7)$$

Here $\lambda_{238}$, $\lambda_{235}$ and $\lambda_{232}$ are decay constant for $^{238}\text{U}$, $^{235}\text{U}$ and $^{232}\text{Th}$ respectively. The value of decay constants are given in table 3 as according to Steiger and Jaeger [1977].

Table 5: Value of Decay constant $\lambda_{238}$, $\lambda_{235}$ and $\lambda_{232}$

<table>
<thead>
<tr>
<th>Decay constant</th>
<th>Value (y$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_{238}$</td>
<td>$1.55\times10^{-10}$</td>
</tr>
<tr>
<td>$\lambda_{235}$</td>
<td>$9.85\times10^{-10}$</td>
</tr>
<tr>
<td>$\lambda_{232}$</td>
<td>$4.95\times10^{-11}$</td>
</tr>
</tbody>
</table>

Using above values of decay constants and using equation (7) we found the gas retention age of Dergaon meteorite as 1.3 Gy.

4.5. Result and Discussion

In this chapter “the ages of Dergaon meteorite we are mainly focussing on cosmic ray exposure ages and gas retention ages. Regarding cosmic ray ages we found three different values i.e. 6.5 My ($T_3$), 10.9 My ($T_{21}$) and 8.8 My ($T_{38}$) respectively. The short exposure age of $T_3$ may have resulted from diffusion loss of $^3\text{He}$ or $^3\text{H}$. This can be explained as follows
As we have seen Ne and $^3$He of Dergaon meteorite are of cosmogenic origin. In a plot of $(^3$He/$^{21}$Ne)$_c$ vs $(^{22}$Ne/$^{21}$Ne)$_c$ ratio in fig.2, the Dergaon meteorite value is plotted below correlation line suggested by Nishiizumi et al (1980) for most ordinary chondrite. The position indicates the possibility of helium loss. The helium loss may have occurred when preatmospheric object of Dergaon meteorite was orbiting in space after delivering from its parent asteroid. The low value $(^3$He/$^{21}$Ne)$_c$ value reflects selective loss of $^3$He compared to Ne-loss. Since about half of $^3$He is produced by beta decay of the radioactive precursor nuclide $^3$H, as pointed by Leya et al (2001). The lowered $(^3$He/$^{21}$Ne)$_c$ ratio may be partially due to $^3$H loss before its radioactive decay ($T_{1/2}$=12.33 yrs) or loss of $^3$He. The $^3$H loss has been explained by higher diffusion rates of $^3$H in metal than in silicate minerals (Leya et al 2001a). However in case of H- chondrite as according to Leya et al (2001), $^3$He production is about 14% of total production in metal phase. Accordingly, at most 7% of cosogenic $^3$He may have been lost from metal phase as $^3$H, if half of $^3$He is produced via $^3$H. Hence the loss of $^3$H produced in metal phase would be insignificant compared with the total loss of $^3$He from the Dergaon meteorite.
Moreover, if $^{21}$Ne is considered retained perfectly cosmogenic, than estimated loss of $^3$He is near about 66% for Dergaon meteorite.

On the other hand, the nominal short $T_{38}$ age of 8.8 My may results from chemical heterogeneity of Dergaon meteorite. Also the sample that being collected from Dergaon meteorite may not represent the bulk Dergaon meteorite, at least for Ca and Fe which are main target element producing $^{38}$Ar by cosmic ray bombardment. Also Ca and Fe concentration plays a significant role in calculation of $T_{38}$ ages, as according to Eugster (1988) equation. There is also a possibility of loss of $^{38}$Ar during weathering as pointed out by Okazaki et al (2000) for E-chondrite. However, this loss can’t play significant role in case of Dergaon meteorite, as the sample being collected within a short period after its fall. This can also find out according to Patzer and Schultz (2001) and Scherer et al (1994). The amount of Kr and Xe and the $^{84}$Kr/$^{132}$Xe ratio in some meteorite increases during terrestrial weathering, accompanied by the loss of cosmogenic $^{38}$Ar. However we didn’t find any increase in Kr for Dergaon meteorite considering trapped component ratio as indicated on fig.3 and fig.4. This confirms the minimum loss of $^{38}$Ar for terrestrial weathering.

![Fig.3: Plot of trapped $^{36}$Ar/$^{132}$Xe vs $^{84}$Kr/$^{132}$Xe. The ratio of Dergaon meteorite is below in the range of ordinary Chondrite](image)
The cosmogenic Ne is mainly produced from Mg silicate phases and they are relatively resistant to weathering. The loss of cosmogenic Ne is comparatively less compared to $^3$He and $^{38}$Ar. Hence we adopt $T_{21}$ as the cosmic ray exposure age of the Dergaon meteorite. Hence we can conclude that cosmic ray exposure age of Dergaon meteorite is 10.9 Ma. This CRE age plotted in fig.5, where Marti and Graf (1992) presented the cosmic ray exposure age of meteorite fall. The probable cosmic ray exposure age of Dergaon meteorite is in the fourth peak.
The calculated K-Ar age indicates that Dergaon meteorite experienced heating effect 1.5 Gy years ago. Since U, Th-He and K-Ar ages are comparative than H-chondrite that shows K-Ar ages of >3 Gy. [Nagao et al 1993, Marti et al 1990]. Therefore, Dergaon meteorite belongs to a group that has a young gas retention age (0.2-1.0) Gy [U, Th-He age] and (.5-1.5) Gy (K-Ar age) [Turner, 1988; Schultz, 1993]. This indicates that the $^4$He and $^{40}$Ar loss probably occurred during the thermal events that happened (1.1-1.5) Gy ago that set He and Ar concentration (Lewis, 1997). The difference between gas retention ages of K-Ar and U, Th-He ages suggested there was mass dependent diffusive loss of $^4$He and $^{40}$Ar and different behaviour of parent nuclides K, U and Th during thermal metamorphism.

In order to find possible mechanism for He loss from Dergaon meteorite we have

the value of $T_3/T_{21}$ from table 1 and $T_4$ and $T_{40}$ from table 4. Now as described by Eugster et al [1993], we have plotted $T_4/T_{40}$ vs $T_3/T_{21}$ ratios in fig.6. According to Eugster et al, if there was preferential loss of He, it would plot at a

![Fig.6: Plot of $T_3/T_{21}$ vs $T_4/T_{40}$ ratios of Dergaon meteorite, Chinese meteorite & Japanese Chondrite are plotted for comparison (Source Okazaki, 2003)](image-url)
point of 1.0 on X and Y axis. If a meteorite loss radiogenic $^4\text{He}$ while it was in present asteroid it shows a value $T_d/T_{40}<1$. The Dergaon meteorite shows a value of $T_d=0.89$, which shows radiogenic $^4\text{He}$ have been partially lost from the cosmic ray irradiation, probably due to high temperature caused by solar radiation. Hence Dergaon meteorite could have an orbital motion with a perihelion close to the sun.
Bibliography

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