Experimentally, the excess heat generation less than the input energy ($Q/Q_{in} < 1$) has been reproduced recently with high probability. But, that more than the input energy is difficult to reproduce even qualitatively except some devices like Arata's Pd black$^{14'')}$ and Patterson Power Cell.$^{24-3)}$ The data sets by Arata et al. where observed the excess heat and helium in the same sample will be treated in Section 11.8 (11.8d).

In this section, we treat only the data sets by Patterson et al., McKubre et al., Ota et al. and R. Oriani

11.3a Patterson Power Cell (PPC)

The PPC invented by J. Patterson in CETI has a complex structure as explained in Chapter 7 (7.1e), Fig. 7.1). The key point of the structure is the bead or the microsphere (ms, made of styrene divinyl benzene) of a diameter 1 mm deposited by Cu-Ni-Pd-Ni multilayer (metal layer) on the surface with a thickness $\sim$ 2 μm. From our point of view, this ms as an element of the cathode of the Cell is of a complex structure covered with $NiLi_x$ and/or $PdLi_x$ and/or Li thin layers on the surface and occludes protium or deuterium in its metal layer effectively.

There are few data sets possible to analyze physics occurring in this system perhaps due to the patent barrier. One scientific data by D. Cravens$^{24'')}$ was analyzed by the TNCF model$^{220,232)}$ and gave a value of $\sim 10^{12}$ cm^{-3} for the parameter n_n in the metal layer. To give this value of the trapped neutron, it should be necessary to have many deuterons in the metal layer in the hydrogen (protium) operation as described in the paper$^{220)}$ to make the breeding reactions (11.7), (11.8) and (11.9) work effectively.

This point will be checked easily if we can get cooperation of researchers in CETI over the patent barrier.

11.3b Data obtained by M. McKubre et al.

Elaborate research works by M. McKubre and his collaborators in SRI International$^{3')}$ gave us an empirical formula (6.1) between the excess energy Q, the electrolyzing current density i and the average density of deuterium relative to Pd atom x in the cathode as given in Chapter 6 (6.1b):

$$Q = M(T)(i - i_0)^a(x - x_0)^b|\frac{\mathrm{d}x}{\mathrm{d}t}|. \qquad (11.25)$$

In this relation, $M(T)$ is a constant depending on the temperature, material and etc., i_0 and x_0 are threshold values of i and x, respectively, and a and b are indices determined by experiments; $a \sim 1$, $b \sim 2$. $|\mathrm{d}x/\mathrm{d}t|$ is the speed of deuterium occlusion or emission.

Notice that the variables in this relation is not independent each other as M. McKubre told in a discussion at a Conference.

Looking at the graph in Fig. 6.2 showing a curve of the above relation and experimental points dispersed widely around the line, we understand that the equation expresses a statistical relation between variables in it with large dispersion. So, we should treat the relation as a statistical one. The threshold values i_0 and x_0 are, also, should be taken as rough marks.

We will try to investigate[221)] the above relation between Q and parameters in the system in terms of TNCF model.

In the light of the model, the cold fusion phenomenon with Li electrolyte in D_2O is interpreted as follows: While the electrolysis proceeds, Pd cathode occludes deuterium in it and also there is formed a layer of PdLi alloy and Li metal on the surface of the cathode. The deuterium in the cathode has inhomogeneity in density highest near the surface in a steady condition. The inhomogeneity of the deuterium density and the surface layer of PdLi layer work as a wall to trap thermal neutrons in the sample. The preliminary period (pre-run) necessary to realize cold fusion recognized sometimes in experiments may be interpreted as a time necessary to form such a structure in and on the cathode to trap neutrons.

With this picture of processes occurring in the experiment, we can give probable dependence of Q on parameters appearing in the above relation to compare with that obtained in the experiment.

Let us write down again pertinent reactions (11.2), (11.4), (11.5) and (11.7):

$$\begin{aligned} n + {}^6_3\mathrm{Li} &= {}^4_2\mathrm{He}\ (2.1\mathrm{MeV}) + t\ (2.7\mathrm{MeV}), \quad Q_1 = 4.8\ \mathrm{MeV}, \\ n + {}^7_3\mathrm{Li} &= {}^8_3\mathrm{Li} = {}^8_4\mathrm{Be}\ (1.2\ \mathrm{keV}) + e^- + \bar{\nu}_e + 13\mathrm{MeV}, \\ {}^8_4\mathrm{Be} &= {}^4_2\mathrm{He}\ (1.6\ \mathrm{MeV}) + {}^4_2\mathrm{He}\ (1.6\ \mathrm{MeV}), \ Q_1' = 16.2\ \mathrm{MeV}, \end{aligned}$$

$$t + d = {}^{4}_{2}\mathrm{He}\ (3.5\mathrm{MeV}) + n\ (14.1\mathrm{MeV}), \quad Q_2 = 17.6\ \mathrm{MeV}.$$

Here, we assume the presence of the trapped neutron in the sample and of ${}^{6}_{3}\mathrm{Li}$ in the electrolyte with its natural abundance is 7.4 %. We will denote the energies liberated in the above first, both second and third, and fourth reactions by Q_1, Q_1' and Q_2, respectively.

Then, the total excess energy Q and the numbers N and N' of the first and the third reactions, respectively, in unit time are given as follows:

$$\begin{aligned} Q &= NQ_1 + N'Q_1' + N\{P_2(Q_2 + Q_3) + P_2'(Q_2 + Q_3')\}. \\ N &= 0.35 n_n v_n n_{Li6} \ell S \sigma_{nLi6}, \\ N' &= 0.35 n_n v_n n_{Li7} \ell S \sigma_{nLi7}. \end{aligned}$$

In the first relation, constants P_2 and P_2' are probabilities of the occurence of the $t - d$ reaction after a $n - {}^{6}\mathrm{Li}$ reaction in the sample and in solution, respectively. The energy Q_3 and Q_3' are the whole energies generated successively in the sample and in solution, respectively, initiated by a neutron with 14.1 MeV produced in the $t - d$ reaction (11.7).

In the above relations, the parameters represent the same meaning as explained hitherto; $0.35 n_n v_n$ is the flux density of the thermal neutrons ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$), n_n and v_n are the density and the thermal velocity of the trapped neutron, respectively, ℓ and S are the thickness and the area of the surface layer on the cathode where Li atoms are precipitated forming PdLi alloy and Li metal layer, n_{Li6} (n_{Li7}) is the density of ${}^{6}_{3}\mathrm{Li}$ (${}^{7}_{3}\mathrm{Li}$) nucleus in the layer. Furthermore, σ_{nL6} (σ_{nL7}) is the fusion cross section of the thermal neutron with ${}^{6}_{3}\mathrm{Li}$ (${}^{7}_{3}\mathrm{Li}$) nucleus.

We will consider a cycle of reactions started from the $n - {}^{6}\mathrm{Li}$ and $n - {}^{7}\mathrm{Li}$ reactions.

First of all, we notice in Fig. 6.2 that the observed points of the excess power density (J $\mathrm{cm}^{-3}\mathrm{s}^{-1}$) at $x = 0.93$ are dispersed between 1.5 and 5.5 with its average value of about 4.5 W cm^{-3}. The average value is similar to that in another experiment by Miles et al.[18″)] where the density of trapped neutrons had been determined as $10^{12} \sim 10^{13}\ \mathrm{cm}^{-3}$. Therefore, we may assume the density of the trapped neutrons in the sample to be $10^{12} \sim 10^{13}\ \mathrm{cm}^{-3}$, though we don't use this value hereafter.

Next, we will consider the first factor, the dependence on the current density, in the above empirical formula (11.24).

The excess energy is proportional to n_n and $n_{Li}\ell$, where

$$n_{Li} = n_{Li6} + n_{Li7}$$

as we can see in the relevant relations. Now, the density of the trapped neutron n_n depends on other parameters because the neutron is lost by the fusion with $^6_3$Li and $^7_3$Li and by going out from the sample and also is supplied by $t-d$ and $d-d$ fusion reactions in the sample, etc. In a situation where the excess heat is produced stationarily, n_n and $n_{Li}\ell$ should be constants. On the other hand, we may assume that the current density of electrolysis is proportional to $n_{Li}\ell$ in the surface layer. Therefore, the excess energy is proportional to the current density in this situation where the above assumptions are valid and the density of the trapped neutron is insensitive to the current:

$$Q \propto i.$$

(This situation occurs where the trapping condition does not change rapidly with ℓ.)

The threshold value i_0 depends on the condition to keep n_n constant for stationary production of excess energy. Where i is too small to feed deuteron and lithium atom to the cathode, formation of the wall to trap neutron will be insufficient to keep the neutrons in the sample. This is the cause of the existence of the threshold value i_0.

Third, let us consider the second factor, the average relative density of deuterium x ($\equiv$D/Pd) in the sample. The density of trapped neutron n_n depends on the distribution of the deuteron density n_d in the sample. In the case of experiments,$^{3')}$ the distribution is not necessarily uniform. In such a case, the inhomogeneity of n_d works positively to trap neutrons in the sample; the larger the inhomogeneity, the higher the density of trapped neutrons. On the other hand, the larger the average value of n_d is, the larger inhomogeneity of n_d is in short time experiment. Therefore, $n_n \propto x$ ($\equiv n_d/n_{Pd}$).

Because n_d is also proportional to $n_{Li}\ell$ in this situation, the excess energy is proportional to the product of $n_{Li}\ell$ and n_n, and therefore is proportional to x^2;

$$Q \propto x^2.$$

The threshold value x_0 is determined, again, by a condition to trap neutrons effectively in the sample. It is conceivable that the trapping is ineffective until x reaches a value to make the unbalance of deuteron distribution large enough to work for the neutron trapping.

Fourth, we will take up the third factor $|\delta x/\delta t|$. This is rather easy to understand. The higher is the speed to occlude (or emit) deuterons, the larger is the inhomogeneity of deuteron distribution which is effective for the trapping of neutrons. Then, $|\delta x/\delta t|$ determines n_n in the sample. Therefore, Q increases in proportion to $|\delta x/\delta t|$:

$$Q \propto |\delta x/\delta t|.$$

Combining three relations deduced above, we obtain the relation (11.24), taking into consideration the fact that these factors are not independent.

11.3c Data obtained by Ota et al.

Using the recipe of data analysis in the TNCF model, we can explain the data of the too large excess heat to explain by chemical reaction obtained by Ota et al.[53∼53''] given in Chapter 6 (6.1g).

The pre-run in the experiment is supposed to be necessary to form the surface layer of Li metal and/or PdLi$_x$ alloy, the thickness ℓ of which has been assumed as 1 μm throughout our analysis. The pre-run is also necessary to accumulate thermal neutron with a density n_n in the sample supplied initially by the background neutron and then by breeding processes, main processes of which were supposed to be the dissociation ones (11.9) and (11.17). These processes are absent in Pd/H/Li system and be a cause of its difference from Pd/D/Li system.

The number N_M of reactions per unit time between the trapped neutron and the nucleus M is related with the density of the trapped neutron n_n by the relation (11.19);

$$N_M = 0.35 n_n v_n n_M V \sigma_{nM} \xi, \tag{11.26}$$

where $0.35 n_n v_n$ is the flow density of the neutron per unit area and time, n_M is the density of the nucleus, V is the volume where the reaction occurs, σ_{nM} is the fusion cross section for the reaction.