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"SUPER-ABSORPTION"

—CORRELATION BETWEEN DEUTERIUM FLUX AND EXCESS HEAT—

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ABSTRACT

The concept of Super-Absorption has been proposed based on the correlation between deuterium flux and excess heat, and based on the selective resonant tunneling model. The experimental evidence for this correlation is shown in the D/Pd system with a Calvet high precision calorimeter. A theoretical model is set-up to show how the resonant tunneling effect will correlate the deuterium flux to the generation of excess heat.

1. INTRODUCTION

When we discuss the nuclear science in condensed matter, the first issue would be how the nuclear reaction rate is affected by the crystal lattice. In other words, we may ask how the wave nature of injected projectile is affected by the crystal lattice of the host metal. This research started from an analogy to optical waves in a crystal lattice.

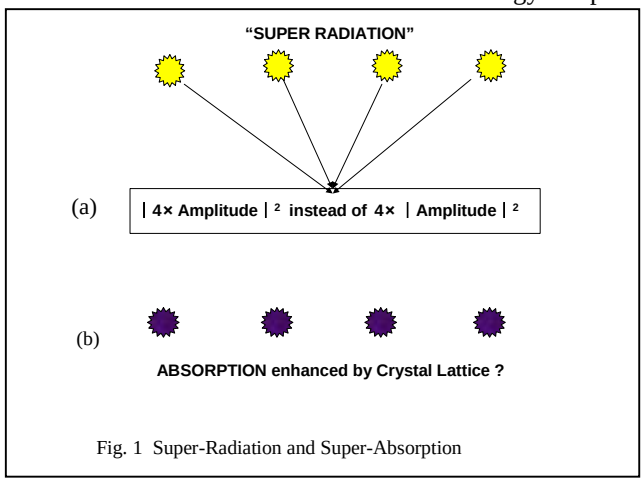

Fig. 1 Super-Radiation and Super-Absorption

In optics, super-radiation[1] due to the coherence between several optical sources has been proved (Fig. 1a). The total intensity of the light is proportional to $|4\times\text{Amplitude of single light}|^2$ instead of $4\times|\text{Amplitude of single light}|^2$ for the case of super-radiation. On the other hand, we might ask what happens if there is coherence between several optical absorbers (Fig. 1b), because any nuclear reaction may be considered as an absorption of the injected wave. When the injected wave hits several absorbers in the lattice, there will be the scattered wave and absorbed wave, the phases of the scattered waves may be in coherence which might result in constructive interference or destructive interference. The constructive interference will enhance the amplitude of the scattered wave inside the lattice; then, it will enhance the absorption when the scattered wave hits the next absorber. The destructive interference will be important when it reduce the amplitude of the total reflected wave because the total reflected wave outside the crystal is the superposition of all reflected waves from all absorbers.

2. SUPER-ABSORPTION IN ONE-DIMENSIONAL MODEL

A series of potential wells and barriers in one dimension are used to illustrate this coherent effect (Fig. 2). The narrow-deep well is the absorber, and the wide-shallow well is the space between absorbers. When the injected wave is coming from the left, we may calculate how much is absorbed, how much is reflected, and how much penetrates this array of lattice well and barrier. Using quantum mechanics[2], for a

single cell of barrier-well-barrier array we may calculate the matrix, M(1), which connects the outgoing wave function, $\Psi_{out}(1)$, and the incoming wave function, $\Psi_{in}(1)$ as:

$$\Psi_{in}(1) = M(1)\Psi_{out}(1) \tag{1}$$

This matrix is written in the plane—wave representation. For example in the case of outgoing wave only (see right-hand-side of Fig.2),

$$\Psi_{out}(1) = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \tag{2}$$

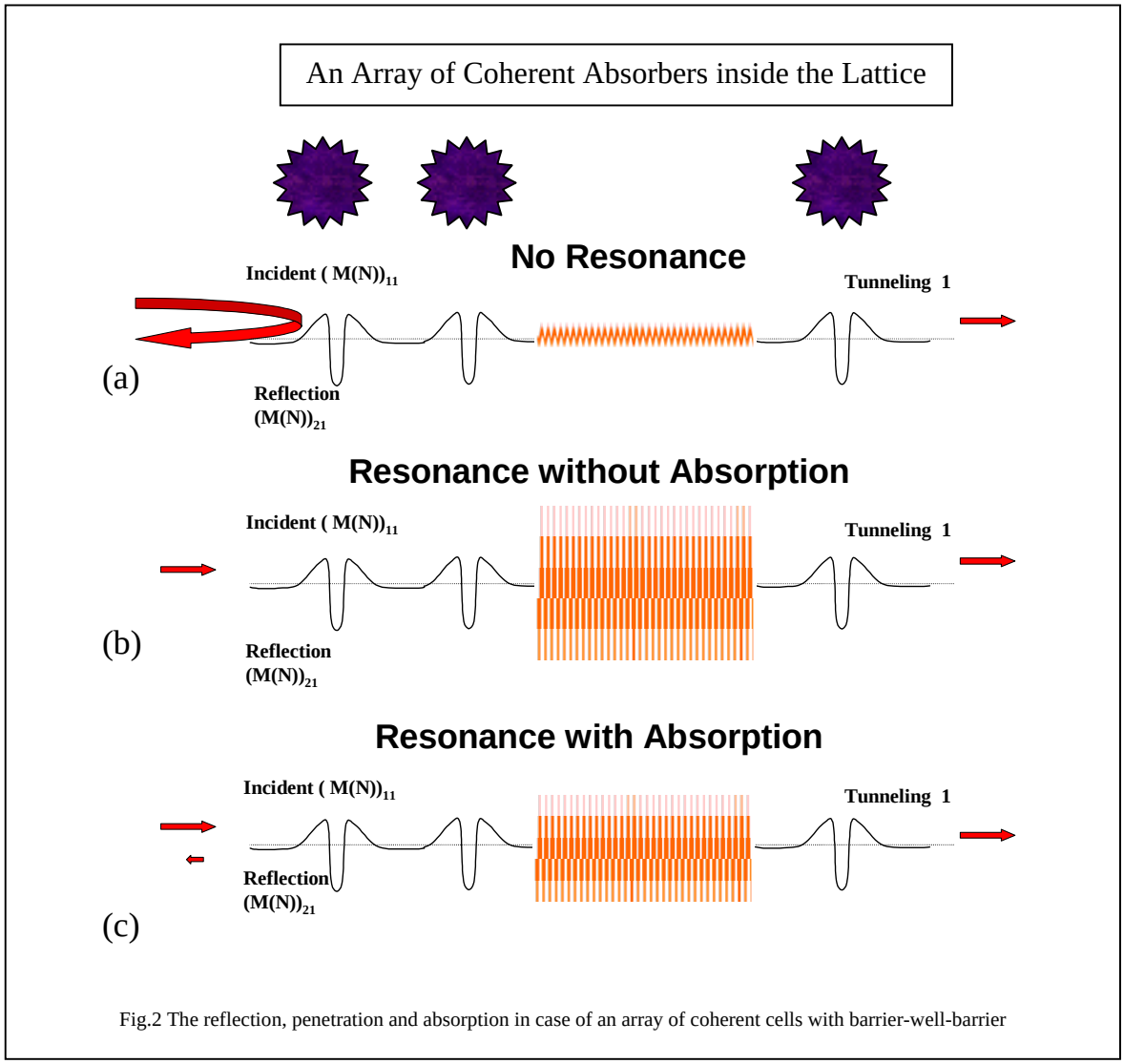

Fig.2 The reflection, penetration and absorption in case of an array of coherent cells with barrier-well-barrier

then, the incoming wave should be

$$\Psi_{in}(1) = \begin{bmatrix} M(1)_{11} \\ M(1)_{21} \end{bmatrix} \tag{3}$$

When the array is increased to a set of N cells of barrier-well-barrier (Fig. 2a), the matrix equation should be written as

$$\Psi_{in}(N) = M(N)\Psi_{out}(N) \tag{4}$$

If we keep the outgoing wave function same as before; then,

$$\Psi_{out}(N) = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \tag{5}$$

Since,

$$M(N) \equiv \begin{bmatrix} M(N)_{11} & M(N)_{12} \\ M(N)_{21} & M(N)_{22} \end{bmatrix} \tag{6}$$

Hence,

$$\Psi_{in}(N) = \begin{bmatrix} M(N)_{11} \\ M(N)_{21} \end{bmatrix} \tag{7}$$

Based on matrix algebra, it can been proved that

$$M(N)_{11} \equiv \frac{\sin[N\alpha]}{\sin[\alpha]} M(1)_{11} - \frac{\sin[(N-1)\alpha]}{\sin[\alpha]} \tag{8}$$

$$M(N)_{21} \equiv \frac{\sin[N\alpha]}{\sin[\alpha]} M(1)_{21} \tag{9}$$

$$\alpha = \arccos[\frac{M(1)_{11} + M(1)_{22}}{2}] \tag{10}$$

The reflection rate, R, penetration rate, T, and the absorption rate, A, may be written as the function of the elements of the connection matrix:

$$R(1) \equiv \frac{\left|M(1)_{21}\right|^2}{\left|M(1)_{11}\right|^2} \tag{11}$$

$$T(1) \equiv \frac{1}{\left|M(1)_{11}\right|^2} \tag{12}$$

$$A(1) \equiv 1 - R(1) - T(1) \tag{13}$$

The similar definition is valid for an array of N set of barrier-well-barrier

$$R(N) \equiv \frac{\left|M(N)_{21}\right|^2}{\left|M(N)_{11}\right|^2} \tag{14}$$

$$T(N) \equiv \frac{1}{\left|M(N)_{11}\right|^2} \tag{15}$$

$$A(N) \equiv 1 - R(N) - T(N) \tag{16}$$

An important conclusion may be drawn from this very general relationship between $M(N)_{21}$ and $M(1)_{21}$ (equation (9): when the reflection rate for single cell is not zero; the total reflection rate for N cell might be zero as long as

$$\frac{\sin[N\alpha]}{\sin[\alpha]} = 0 \tag{17}$$

In physics, this is the result of destructive interference among all the reflected waves. At the same time R(N)=0 implies T(N)$\rightarrow$1 when there is no absorption(Fig. 2b). It means a constructive interference among all

the propagating waves inside the array of barrier-well-barrier region which enhances the penetration rate greatly. The conservation of the probability guarantees the eventual penetration after all the reflection and penetration in each cell.

Now we may find another important conclusion from this relationship: when a small imaginary potential is introduced in the well region of the absorbers; then, there will be an absorption rate (Fig. 2c):

$$A(N) = 1 - R(N) - T(N) \tag{18}$$

It is proportional to the product of imaginary part of the potential and the square of the amplitude of the wave function, $\mathrm{Im}(U_1)\times|\Psi_1(N)|^2$, which has been greatly enhanced due to the constructive interference among all the propagating waves inside the array of cells. It is a kind of resonant tunneling. Here, $\mathrm{Im}(U_1)$ is the imaginary part of the potential in the absorber region; $|\Psi_1(N)|$ is the average amplitude of the wave function in that region. This resonant tunneling predicts that the peak of the penetration rate will be accompanied with a peak of the absorption peak. i.e. the correlation between the flux and the reaction rate.

In analogy to the selective resonant tunneling model[3,4,5], we may anticipate that the imaginary potential can not be too large or too small. It is evident that the absorption rate $A(N)\rightarrow 0$ if this imaginary potential $\mathrm{Im}(U_1)\rightarrow 0$. On the other hand if this imaginary potential is too large; then, it will damp the resonance such that the product of $\mathrm{Im}(U_1)\times|\Psi_1(N)|^2\rightarrow 0$. Thus there must be a maximum for a certain value of $\mathrm{Im}(U_1)$ in between. This selectivity will explain why only certain channel of reaction is open to the resonant tunneling. In other words, the absorption peak will reach its maximum when the imaginary part of the potential reaches a certain intermediate value. Indeed, it implies that only the nuclear reaction without strong neutron and gamma radiation would be selected by this resonant tunneling mechanism.

3. EXPERIMENTAL EVIDENCE FOR THIS CORRELATION.

The first evidence was from the "pumping effect" in the gas loading system[6] Every time we started pumping out the gas, the temperature of the deuterium-loaded Pd wire will jump up. It is quite stubborn and reproducible. However, there were two items which have to be improved: (1) we need an independent calorimeter to measure the heat flow from the D/Pd system, because the temperature jump of D/Pd wire might be induced by the change of heat transfer coefficient during the pumping; (2) we have to find the direct evidence which shows a deuterium flux through the Pd crystal. A Calvet calorimeter(C-80D, Setaram) has been used as the independent calorimeter. It measures the heat flow through the surface which enclosed the reaction cell. It does not depend on the heat transfer coefficient of the D/Pd system, and it does not require a thermal equilibrium of D/Pd system. A thin wall Pd tube is inserted in to the reaction cell (Fig.3b). One end of the Pd tube is sealed, and the other end is connected to a deuterium gas bottle. At room temperature when we pump out the gas in the reaction cell, the deuterium gas permeating through the

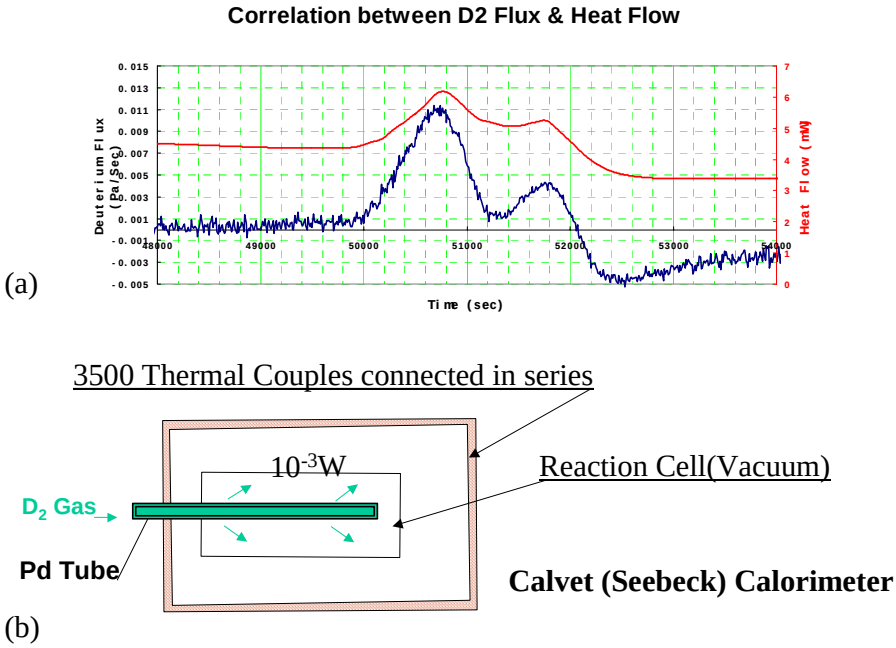

Fig. 3 Schematics of Calvet calorimeter and the curves showing correlation between deuterium flux(smooth line, right scale) and heat flow (zigzag line, left scale)

thin-wall of Pd tube is negligible. When we enhance the temperature of Pd tube; then, stop the heating and let it cooling down gradually, there will be a flux through the thin-wall of Pd tube at certain temperature. The gas pressure inside the Pd tube decreases quickly, and the pressure outside the Pd tube increases quickly even if the vacuum pump is working continuously to pump out the gas in the reaction cell. In the meanwhile a heat flow is detected by this Calvet calorimeter. The precision of this Calvet calorimeter is in the order of 20 microwatts; however, the heat flow detected is in the order of 4 milliwatts. The deuterium flux may decrease and increase again when the temperature of D/Pd system is decreasing, and the heat flow will decrease and increase correspondingly (Fig. 3a). It is evident that the higher deuterium flux corresponds to the higher heat flow, and the peak position of the heat flow is a little delayed with respect to the peak of deuterium flux due to the time constant of C-80D (100-250 seconds). This heat flow experiment has been repeated 16 times. It is backed up by the nitrogen gas experiment (no flux and no heat flow), and the calibration with a standard electrical heater(error bar is less than 20 μW)..

4. DISCUSSION

(1) The nature of the deuterium flux is not diffusive only. For a long time we believe that the permeation of deuterium gas through the palladium is a diffusion process in nature[7]. Usually the diffusion coefficient decreases quickly when the temperature is decreasing ; however, it is clearly shown that the flux might be enhanced when the temperature of Pd is decreasing (Fig.3a). This part of flux is apparently related to a resonant process. It implies that a single deuteron wave function might be applied to the whole D/Pd system as suggested by Professor M. Fleischmann[8] who has searched this multi-body feature in condensed phase for more than 4 decades. Indeed this is the basic assumption in the above-mentioned calculation. An indirect evidence might be drawn from the Cold Neutron experiment carried out at NIST in US[9]. When cold neutron was injected to a heavy-water-ice target, the absorption rate shows clear dependence on the wave length of the cold neutron (5Å to 9Å), and a clear dependence on the temperature of the target (25° to –7°C). These peak-wise dependences disappear when the target is switched to light-water-ice. As we know, the crystal structure is almost same for both heavy-water-ice and light-water-ice. The difference is in the nuclear reaction for neutron absorption. The neutron absorption reaction in the heavy-water-ice is much more weaker than that in the light-water-ice. The long mean free path is necessary for the resonant tunneling in the heavy-water-ice, and it results in the peak-wise absorption rate in the heavy-water-ice.

(2) Super-Absorption versus super-radiation. In optics, the super-radiation means that the intensity of the

light would be proportional to the square of the number of the individual light sources; then, what happens to the super-absorption? We found that in the case of super-absorption the minimum value of the escaping rate would be proportional to $\frac{1}{N^x}$. Here, 1< x < 2, N is the number of the coherent absorbers. The escaping rate is defined as the sum of reflection rate and the penetration rate, i.e.

$$(R_N + T_N)_{\min} \propto \frac{1}{N^x} \tag{19}$$

In comparison, for the non-coherent absorption the minimum value of the escaping rate would be still proportional to $\frac{1}{N^x}$, but 0 < x < 1. It implies that in case of non-coherent absorption the absorption rate will increase with the number of the absorbers, but it is not as fast as that in the case of coherent absorption. In physics, in the case of non-coherent absorbers, the absorbers on the surface will shade the absorbers in the bulk; hence, x <1. In contrary, the coherent absorbers in the bulk will produce the reflecting wave to interfere with the reflecting wave on the surface such that the total reflection is reduced; hence, x > 1. x can not be greater than 2, because the shading effect is still there even if in the case of coherent absorbers.

(3) The nuclear nature of the heat flow. What is the origin of this heat sources? Was it the energy of solution? No, because it was a flux, the energy of solution must be balanced with the energy of dissolution. Was it the Joule-Thomson effect? No, because the J-T effect is very small. It is detectable only if the pressure difference is in the order of several hundred atm. In our experiments, the pressure difference across the thin wall of Pd tube is less than 2 atm. The J-T effect is in the order of microwatt. In order to find the nuclear nature of the heat flow, TLD (Thermoluminescence detector) was placed inside the reaction cell just next to the Pd tube. It will record any nuclear radiation inside the reaction cell during the whole process. It was found that the recorded radiation in foreground was always a little higher than the background.[10] Since TLD is only sensitive to the radiation with energy greater than 20 keV. It is an evidence of the nuclear nature of this heat flow.

(4) The feasibility of self-sustaining heat flow If we are able to keep this heat flow as long as one year, then, the total amount of heat energy released will be so great that only the nuclear energy is comparable. However, in our experiments the heat flow lasted only several tens of minutes. If we are able to enhance the heat flow by a factor of 100; then, it is feasible to balance the heat transfer with the heat flow generated. Then we may be able to realize the self-sustaining heat flow. Hopefully, we shall be able to do it with multiple-layer thin-film technique. Indeed we have reached several hundred milliwatts of excess heat in a same size of Pd tube already in terms of a current heating.[11]

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