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# Generalized Theory of Bose-Einstein Condensation Nuclear Fusion for Hydrogen-Metal System

Yeong E. Kim
Department of Physics
Purdue University
West Lafayette, Indiana 47907, USA
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## ABSTRACT

Generalized theory of Bose-Einstein condensation nuclear fusion (BECNF) is used to carry out theoretical analyses of recent experimental results of Rossi et al. for hydrogen-nickel system. Based on incomplete experimental information currently available, preliminary theoretical explanations of the experimental results are presented in terms of the generalized BECNF theory. Additional accurate experimental data are needed for obtaining more complete theoretical descriptions and predictions, which can be tested by further experiments.

## I. Introduction

Over the last two decades, there have been many publications reporting experimental observations of excess heat generation and anomalous nuclear reactions occurring in metals at ultra-low energies, now known as ‘low-energy nuclear reactions’ (LENR). Theoretical explanations of the LENR phenomena have been described based on the theory of Bose-Einstein condensation nuclear fusion (BECNF) in micro/nano-scale metal particles [1-3]. The BECNF theory is based on a single basic assumption capable of explaining the observed LENR phenomena; deuterons in metals undergo Bose-Einstein condensation. While the BECNF theory is able to make general qualitative predictions concerning LENR phenomena it is also a quantitative predictive physical theory. Some of the theoretical predictions have been confirmed by experiments reported recently. The BECNF theory was generalized for the case of two species of Bosons [4].

Recently, there were two positive demonstrations (January and March, 2011) of a heat generating device called “Energy Catalyzer” [5]. The Energy Catalyzer is an apparatus built by inventor Andrea Rossi, Italy. The patent application [5] states that the device transforms energy stored in its fuel (hydrogen and nickel) into heat by means of nuclear reaction of the two fuel components, with a consequent observed production of copper [5,6]. According to Rossi’s patent application [5], heating of the sample is accomplished by an electric resistance heater. Details of March 2011 demonstration were reported by Essen and Kullander [7]. The report [7] also contains references to January 2011 demonstration. In the following, we describe hydrogen-nickel reactions in section II. Other possible reactions are discussed in section III. Conclusions are given in section IV.

## II. Hydrogen-Nickel Reactions

The generalized BECNF theory [4] can be applied to the case of hydrogen-nickel fusion reactions observed in Rossi's device (the energy catalyzer) [5] under the following two conditions: (1) additives used (not disclosed in the patent application) form Ni alloy and/or Ni metal/alloy oxide in the surface regions of nickel nano-scale particles, so that Ni atoms/nuclei become mobile with a sufficiently large diffusion coefficient and (2) local magnetic field is very weak in the surface regions, providing a suitable environment in which two neighboring protons can couple their spins anti-parallel to form spin-zero singlet state (S=0). Relatively low Curie temperature (nickel has the Curie temperature of 631 $^{o}$K (~358 $^{o}$C)) is expected to help to maintain the weak magnetic field in the surface regions. If Rossi's device is operated at temperatures greater than the Curie temperature ~ 358 $^{o}$C and with hydrogen pressures of up to ~ 22 bars, the conditions (1) and (2) may have been achieved in Rossi's device.

The mobility of Ni atoms/nuclei (condition (1)) is enhanced by the use of an electric resistance heater to maintain higher temperatures. This may provide a suitable environment in which more of both Ni atoms/nuclei and protons become mobile, thus creating a favorable environment for the case of two species of Bosons (Ni nuclei and composite Bosons of paired two protons). If the velocities of mobile Ni atoms/nuclei under the condition (1) are sufficiently slow, their de-Broglie wavelengths become sufficiently large and may overlap with neighboring two-proton composite Bosons which are also mobile, thus creating Bose-Einstein condensation of two species of Bosons. The generalized BECNF theory can now be applied to these two-species of Bosons and provides a mechanism for the suppression/cancellation of the Coulomb barrier, as shown in [4].

Once the Coulomb barrier is overcome in the entrance reaction channel, many possible allowed exit reaction channels may become open such as reactions (i) $^{A}$Ni(2p(S=0), p)$^{A+1}$Cu, with even A=58, 60, 62 and 64. These reactions will produce radioactive isotopes $^{59}$Cu and $^{61}$Cu with A = 58 and 60, respectively. $^{59}$Cu has a half-life of 81.5 seconds and decays by the electron capture to the $^{59}$Ni ground state (58.1%) which has a half-life of 7.6 x $10^{4}$ years and to the $^{59}$Ni excited states (41.9%) which in turn decay to the $^{59}$Ni ground state by emitting gamma-rays with energies ranging from 310.9 keV to 2682.0 keV [8]. $^{61}$Cu has a half-life of 3.333 hours and decays by the electron capture to the stable $^{61}$Ni ground state (67%) and to the $^{61}$Ni excited states (33%) which in turn decay to the $^{61}$Ni ground state by emitting gamma-rays with energies ranging from 67.412 keV to 2123.93 keV [8]. Gamma-rays (and neutrons) have not been observed outside the reactor chamber during the experiment [6]. These gamma-rays may have been present inside the reaction chamber. If no radiations are observed, reactions (i) are ruled out.

Focardi and Rossi [6] reported that the experimental results of Rossi et al. indicate the production of stable isotopes $^{63}$Cu and $^{65}$Cu with an isotopic ratio of $^{63}$Cu /$^{65}$Cu ~ 1.6 (natural abundance is $^{63}$Cu/ $^{65}$Cu = 2.24). This production of Cu may be due to reactions (i). The production of $^{63}$Cu and $^{65}$Cu with isotopic ratio of $^{63}$Cu /$^{65}$Cu different from the natural isotopic ratio is expected and can be explained by estimating the reaction rates for $^{62}$Ni(2p(S=0), p)$^{63}$Cu and $^{64}$Ni(2p(S=0), p)$^{65}$Cu. Reaction rates estimates based on transmission probability calculated from a barrier tunneling model similar to the alpha-decay theory indicate that the reaction rates for stable Cu productions, $^{62}$Ni(2p(S=0), p)$^{63}$Cu and $^{64}$Ni(2p(S=0), p)$^{65}$Cu, are expected to be much larger than the reaction rates for production of radioactive Cu, $^{58}$Ni(2p(S=0), p)$^{59}$Cu and $^{60}$Ni(2p(S=0), p)$^{61}$Cu. This leads to the prediction that intensities of the gamma-rays from the decays of $^{59}$Cu and $^{61}$Cu are expected to be weak and do not commensurate with the observed heat production, which is mostly from stable Cu production reactions $^{62}$Ni(2p(S=0), p)$^{63}$Cu and $^{64}$Ni(2p(S=0), p)$^{65}$Cu.

There are other exit reaction channels which are (nearly) radiation-less, such as reactions (ii) $^{A}$Ni(2p(S=0), α)$^{A-2}$Ni, (even A=58, 60, 62, and 64) [9]. For this case, we expect that the natural isotopic ratio of Ni isotopes will be changed in a particular way, which can be checked from the sample after each experiment. Even though reactions (ii) produce radioactive isotope $^{56}$Ni, it can be shown using the alpha-decay theory that its reaction rate is much slower (by many order of magnitudes) than those of other reactions.

Other exit reaction channels, $^{A}$Ni(2p(S=0), d)$^{A}$Cu, $^{A}$Ni(2p(S=0), $^{3}$He)$^{A-1}$Ni, and $^{A}$Ni(2p(S=0), t)$^{A-1}$Cu (all with even A=58, 60, 62, and 64) are ruled out since these reactions all have negative Q-values. There are possibilities of neutron-emission exit reaction channels, such as reactions (iii) $^{A}$Ni(2p(S=0), n)$^{A+1}$Zn, (even A= 62, and 64; Q is negative for A = 58 and 60). However, reaction rates for reactions (iii) are expected be substantially smaller than those for reaction (i). Reactions (iii) involve emission of a tightly bound neutron ($^{62}$Ni → $^{61}$Ni + n, Q = -10.597MeV or $^{64}$Ni → $^{63}$Ni + n, Q = -9.657MeV) while reactions (i) involve emission of a loosely bound proton from an excited compound nuclear state consisting of $^{A}$Ni (even A) and 2p(S=0). Therefore, the transmission probability of a neutron tunneling through the centrifugal barrier in reactions (iii) is expected to be substantially smaller than that of a proton tunneling through the centrifugal barrier in reactions (i).

The branching ratios of reactions (i) and (ii) need to be determined by measurements of gamma-ray energies and changes in isotopic ratios from future Ross-type experiments. Theoretically, the branching ratios can be estimated by calculating transmission probability of an emitted charged particle tunneling through both Coulomb and centrifugal barriers in the exit reaction channel, as done in the alpha-decay theory.

## III. Other Possible Reactions

In addition to the above reactions described in II, there are possibilities of reactions involving additives used (not disclosed so far). For an example, if lithium is added as an additive, reaction (iv) $^{6}$Li(2p(S=0), p $^{3}$He)$^{4}$He may be possible. As in cases of reactions (i) and (ii), Ni nano-particles would be still playing an important role of providing two-proton singlet composite Bosons for reaction (iv). Reaction (iv) would not change the isotopic ratios of Ni.

## IV. Conclusions

In order to explore validity and to test predictions of the generalized BECNF theory for the hydrogen-metal system, it is very important to carry out Rossi-type experiments independently in order to establish what are exact inputs and outputs of each experiment. If the entrance and exit reaction channels are established experimentally, we can investigate selection rules as well as estimates of the reaction rates for different exit reaction channels, based on the generalized

BECNF theory [1-4]. Once these experimental results are established, further application of the generalized BECNF theory can be made for the purpose of confirming the theoretical mechanism and making theoretical predictions, which can then be tested experimentally.

Basic description of the above theoretical concepts for BECNF in the hydrogen-metal system will be included in an invited talk at a forthcoming nuclear physics conference [10], and will be published in the conference proceedings [10].

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PDF-files of [1-3] are available at:

http://www.physics.purdue.edu/people/faculty/yekim.shtml