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On the Nature of Dark Matter and Quark-Gluon Plasma (QGP): The Generation of the Nature's Basic Elements and QGP Phase Diagram: A Novel Millennium Power Plant Reactor Proposal

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Abstract

This paper presents a novel physical interpretation of the state of matter of the quark-gluon as the most fundamental building blocks in nature. Such a model is derived based on the assumption that dark matter and dark energy behave as a perfect ideal fluid at extremely high temperature. By the virtue of Boltzmann constant of the ideal gas law and NASA's Cosmic Microwave Background Explorer (CMB) which estimated that the space has an average temperature close to 2.7251 Kelvin, then the equivalent mass-energy of the fundamental particle of the dark matter/dark energy is determined. Moreover, assuming a uniform space dark energy/dark matter density, then the critical temperature at which the dark matter has a unity entity per volume is identified as $64 \times 10^{12} K$. The calculated critical temperature of the quark-gluon plasma is found to be proportional to the temperature generated by colliding heavy ions at the Relativistic Heavy Ion Collider (RHIC) and European Organization for Nuclear Research (CERN). Moreover, the individual critical temperature of the quark-gluon plasma matter at which the elements of the periodic table are generated is explicitly determined. The generation temperature trend of the elements of the periodic table groups and periods are then demonstrated. Accordingly, the phase diagram of the quark-gluon state matter is proposed. Finally, a new model of quark-gluon power generation plant is proposed and aims to serve humanity with new energy sources in the new millennium.

1. Introduction

Recent astronomical observations by the cosmic microwave background (CMB), Supernova Cosmology Project, and High-z Supernova Search Team have provided strong evidence that our universe is not only expanding, but also expanding at an accelerating rate [3-10]. Dark Energy was proposed for the first time in 1998 when two groups of astronomers made a survey of exploding stars, or supernovas Ia, in a number of distant galaxies [3] [5]. Those researchers found that the supernovas were dimmer than they should have been and were farther away than they should have been. The astronomers realized that the only way for that to happen if the expansion of the universe

had sped up at some time in the past which should account for a significant portion of a missing component in the universe [19]. The only explanation is that there is a kind of force that has a strong negative pressure acting outward in opposition to gravitational force at large scales which was proposed for the first time by Einstein in his General Relativity and given the name the cosmological constant Λ [1]. This force is given the name Dark Energy since it is transparent and cannot be observed or detected directly. A thermodynamics model is proposed to account for the dark energy in [22]. Cosmological observations strongly suggest that the universe is dominated by a smoothly homogenous distributed dark energy component [11-21]. It is worth to mention that NASA's Cosmic Microwave Background Explorer (CMB) in 1992 estimated that the sky has a temperature close to 2.7251 Kelvin. Moreover, the Wilkinson Microwave Anisotropy Probe (WMAP) in 2003 has made a map of the temperature fluctuations of the CMB with more accuracy [11]. Furthermore, the measurements of the Wilkinson Microwave Anisotropy Probe (WMAP) satellite indicate the universe has a flat geometry [25-26] [29] [38].

Using the Doppler Shift phenomena, scientists can learn much about the motions of galaxies. When scientists look closer at the speeds of galactic rotation, they find something strange. Based on Keplerian physics, the individual stars in a galaxy should act like the planets in our solar system—the farther away from the center, the slower they should move. On the contrary, the Doppler Shift reveals that the stars in many galaxies do not slow down at farther distances [3] [11]. Particularly, observations reveal that the stars move at flat speeds that should rip the galaxy apart because there is not enough measured mass to supply the gravity needed to hold the galaxy together. These high rotational speeds suggest that the galaxy contains more mass than was calculated. Scientists theorize that, if the galaxy was surrounded by a halo of unseen matter, the galaxy could remain stable at such high rotational speeds. Accordingly, dark matter can be defined as the unseen matter of unknown composition that does not emit or reflect enough electromagnetic radiation to be observed directly, but its presence can be inferred from gravitational effects on visible matter like galaxies and stars. Based on the Lambda-Cold Dark Matter Model (Lambda-CDM 2006), dark energy contributes about 70% of the critical density and has a negative pressure [25-26]. The cold dark matter contributes 25% [3-5] [11][18-20] [38-39]. Meanwhile, Hydrogen, Helium and stars contributes 5% and, finally the radiation contributes 5×10^{-5} . According to present observations of structures larger than galaxy-sized as well as Big Bang cosmology, dark matter accounts for the vast majority of mass in the observable universe (22%). The observed phenomena consistent with dark matter observations include the rotational speeds of galaxies, orbital velocities of galaxies in clusters, gravitational lensing of background objects by galaxy clusters, and the

temperature distribution of hot gas in galaxies and clusters of galaxies.

A quark-gluon plasma (QGP) can be defined as a phase of quantum chromodynamics (QCD) which exists at extremely high temperature and/or density. This phase consists of (almost) free quarks and gluons, which are several of the basic building blocks of matter. Recent analyses from the Relativistic Heavy Ion Collider (RHIC), a 2.4-mile-circumference (atom smasher) at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory, establish that collisions of gold ions traveling at nearly the speed of light have created matter at a temperature of about 4 trillion degrees Celsius — the hottest temperature ever reached in a laboratory, about 250,000 times hotter than the center of the Sun [31-35]. This temperature, based upon measurements by the PHENIX collaboration at RHIC, is higher than the temperature needed to melt protons and neutrons into a plasma of quarks and gluons. These new temperature measurements, combined with other observations analyzed over nine years of operations by RHIC's four experimental collaborations — BRAHMS, PHENIX, PHOBOS, and STAR — indicate that RHIC's gold-gold collisions produce a freely flowing liquid composed of quarks and gluons. Such a substance, often referred to as quark-gluon plasma, or QGP, filled the universe a few microseconds after it came into existence 13.7 billion years ago.

RHIC has created a new state of hot, dense matter out of the quarks and gluons that are the basic particles of atomic nuclei, but it is a state quite different and even more remarkable than had been predicted. When nuclear matter is heated beyond 2 trillion degrees, it becomes a strongly coupled plasma of quarks and gluons. Experiments using highly energetic collisions between heavy nuclei have revealed that this new state of matter is a nearly ideal, highly opaque fluid [40].

The expansion of hot and dense matter created in a heavy ion collision at RHIC is controlled by an equation of state which describes the dependence of the pressure in the medium on its energy density. Knowledge of the equation of state is, for instance, indispensable for a correct hydrodynamic modeling of the expansion of the transient form of matter created in a gold-gold collision at RHIC [41]. The new results on the equation of state show features familiar from earlier approximate calculations; a rapid rise of the energy density in the transition region at about 1 GeV/fm³ or a temperature of about 190 MeV and a comparatively slow increase of the pressure which comes close to that of a quasi-free quark-gluon gas only at temperatures of about 600 MeV. In fact, even at these high temperatures it stays about 10% below the ideal gas limit, which is known to be reached eventually at extremely high temperatures. High statistics results on large lattices are obtained for bulk thermodynamic observables, i.e. pressure, energy and entropy density, at vanishing quark chemical potential for a wide range of temperatures,

140 MeV $\leq T \leq$ 800 MeV.

This paper introduces a novel physical interpretation of the state of matter of the quark-gluon as the most fundamental building blocks in nature. Such a model is derived based on the assumption that dark matter and dark energy behave as a perfect ideal fluid at extremely high temperature as presented in Section 2. By the virtue of Boltzmann constant of the ideal gas law and NASA's Cosmic Microwave Background Explorer (CMB) which estimated that the space has an average temperature close to 2.7251 Kelvin, then the equivalent mass-energy of the fundamental particle of the dark matter/dark energy is determined. The calculated critical temperature of the quark-gluon plasma is found to be proportional to the temperature generated by colliding heavy ions at the Relativistic Heavy Ion Collider (RHIC) and European Organization for Nuclear Research (CERN). Moreover, assuming a uniform space dark energy/dark matter density, then the critical temperature at which the dark matter has a unity entity per volume is identified as $64 \times 10^{12} K$ as derived in Section 3. The quark-gluon standard model of the proton and Neutron is presented in Section 4. Then, an isothermal expansion model of the universe is proposed in Section 5. Moreover, the individual critical temperature of the quark-gluon plasma matter at which the elements of the periodic table are generated is explicitly determined in Section 6. The generation temperature trend of the elements of the periodic table groups and periods are then demonstrated. Accordingly, a novel phase diagram of the quark-gluon state matter is proposed and a new model of quark-gluon power generation plant is proposed in Section 7 that aims to serve humanity with new energy sources in the new millennium. Finally, conclusions are presented in Section 8.

2. Preliminary Review on the Basic Blocks of the Universe

This state of matter equation relates the pressure P , temperature T and the volume V of a substance behaves as an ideal gas [2], that is

$$PV = mRT \quad (1)$$

As it can be seen easily that equation (1) represents the energy associated with an ideal gas at given pressure P , temperature T and the volume V , that is

$$PV = mRT = E \quad (2)$$

Note that both sides of the equation has the units of energy (work done by pressure P). Assume now that dark energy behaves like an ideal gas with a negative pressure ($-P$) that causes the universe to expand with a total volume V , then by dividing both side of the equation of state (5) by V , then

$$P = \frac{m}{V} RT = \frac{E}{V} \quad (3)$$

Defining the mass density as $\rho_m = \frac{m}{V}$ and energy density as $\rho_E = \frac{E}{V}$, equation (3) yields to

$$P = \rho_m RT = \rho_E \quad (4)$$

Now by taking the ratio between the mass density and energy density then

$$\frac{\rho_E}{\rho_m} = RT \quad (5)$$

It can be concluded that the ratio between the mass density and energy density are proportional to the product of the temperature T and dark energy-dark matter constant R (known as Universal gas constant).

The Boltzmann constant K_B is a physical constant that relates temperature to microscopic energy. $K_B = R / N_A$, where N_A is the Avogadro Number. $K_B = 1.38 \times 10^{-23} J / K$. The numerical value of K_B measures the conversion factor for mapping from this microscopic energy E to the macroscopically-derived temperature scale.

The ideal gas law can now be expressed in terms of Boltzmann constant such that

$$PV = NK_B T \quad (6)$$

where N is the actual number of entities (particles). Now dividing both sides of (10) by volume to get the energy density then

$$P = \frac{N}{V} K_B T = \rho_N K_B T = \rho_E \quad (7)$$

This shows that the ratio between the energy density and the entities density is proportional to the absolute temperature times the Boltzmann constant.

The ideal gas law can now be expressed in terms of Boltzmann constant such that

$$PV = Nk_B T = E \quad (8)$$

where N is the actual number of molecules. Now dividing both sides of (8) by the volume to get the energy density then

$$P = \frac{N}{V} k_B T = \rho_N k_B T = \rho_E \quad (9)$$

By taking the ration between the energy density ρ_E and number of molecules density N/V , one gets

$$k_B T = \frac{\rho_E}{\rho_N} \quad (10)$$

or

$$\rho_N = \frac{\rho_E}{k_B T} \quad (11)$$

This shows that the ratio between the energy density and the molecular density is proportional to the absolute temperature times the Boltzmann constant. The simulation results demonstrate such a model.

3. Dark Matter, Its Critical Temperature and Physical Properties

WMAP [10] determined that the universe is flat, from which it follows that the mean energy density in the universe is equal to the critical density (within a 1% margin of error). This is equivalent to a mass density of $9.9 \times 10^{-30} \text{ g/cm}^3$, which is equivalent to only 5.9 protons per cubic meter.

$$\begin{aligned}\rho_E &= 9.9 \times 10^{-30} \text{ gm/cm}^3 = 9.9 \times 10^{-27} \text{ kg/m}^3 \\ &= 8.8981 \times 10^{-10} \text{ J/m}^3 = 5.5302 \times 10^9 \text{ eV/m}^3 \quad (12) \\ &= 5.5302 \text{ GeV/m}^3\end{aligned}$$

Now the equation of state can be expressed as a function of the number of entities per cubic meter such that,

$$T = \frac{\rho_E}{\rho_N K_B} = 6.4478 \times 10^{13} \frac{1}{\rho_N} \text{ K} = \frac{64.478}{\rho_N} \text{ TK} \quad (13)$$

The temperature at which one entity would be generated called in this work as the critical temperature and equals to 64 Tetra Kelvin. It is desired now to calculate the critical temperature at which 5.9 protons per cubic meter were produced. By the virtue of the ideal state equation, it yields

$$\begin{aligned}T &= \frac{\rho_E}{\rho_N K_B} = \frac{8.8981 \times 10^{-10} \text{ J/m}^3}{5.9 \times 1.38 \times 10^{-23} \text{ J/K}} = 10.92910^{12} \text{ K/m}^3 \\ &= 10.929 \text{ Tetra K/m}^3 = 10.929 \text{ TK/m}^3\end{aligned} \quad (14)$$

It implies that 10.929 Trillion Kelvin degrees were needed to produce an equivalent 5.9 protons per cubic meter of mass-energy critical density. Furthermore, ρ_N is unity when the temperature T is equal to $64.479 \times 10^{12} \text{ K}$ (this would be the temperature to generate 1 protons per cubic meter).

Based on astronomical observations that the average density of dark matter and dark energy is approximately:

$$\begin{aligned}\rho_{DM} &= 0.23 \times 9.9 \times 10^{-30} \text{ gm/cm}^3 = 2.2770 \times 10^{-27} \text{ kg/m}^3 \\ &= 2.0466 \times 10^{-10} \text{ J/m}^3 = 1.2719 \times 10^9 \text{ eV/m}^3 \quad (15) \\ &= 1.2719 \text{ GeV/m}^3\end{aligned}$$

Now benefiting from (11) at which CMB temperature is $T=2.73 \text{ K}$, then

$$\rho_N = 6.4480 \times 10^{12} \text{ entities / m}^3 \quad (16)$$

Since $\rho_N = 6.4480 \times 10^{12} \text{ entities / m}^3$ is corresponding to

$2.2770 \times 10^{-27} \text{ kg/m}^3$, then each entity has a mass of $2.2770 \times 10^{-27} \text{ kg/m} / 6.4480 \times 10^{12} = 3.5313 \times 10^{-40} \text{ Kg}$. This may serve as the most fundamental particle in nature and represent the basic block of the quarks and gluons. Such a mass $3.5313 \times 10^{-40} \text{ Kg}$ is equivalent to $3.1739 \times 10^{-23} \text{ J} = 1.9726 \times 10^{-4} \text{ eV} = 0.19726 \text{ meV}$. It can be noticed that this particle mass $3.1739 \times 10^{-23} \text{ J}$ is proportional to Boltzmann constant $K_B = 1.38 \times 10^{-23} \text{ J/K}$.

Moreover, considering the lowest temperature in nature at Boomerang nebula which is 1 Kelvin, then the dark matter should be exactly equivalent to Boltzmann constant, which is $m_b = 1.38 \times 10^{-23} \text{ J}$.

As it can be seen, the mass of the electron is much heavier than this candidate particle by 2.5796 billion times, meanwhile, the proton weighs 4.7365 trillion (4.7365×10^{12}) of dark matter particles. The atomic mass unit $\text{atmu} = 0.93146 \text{ GeV/c}^2$. Now let us compare the mass of the dark matter particle to the standard value of (atmu), which leads to the conclusion that 4.7220 Trillion (4.7220×10^{12}) dark matter particles are required to construct 1 unity of atomic mass unit. In other words, each dark matter particle weighs (2.1177×10^{-13}) atmu.

It is possible now to calculate the virtual momentum that dark matter particle possesses as follows:

$$\bar{p} = E / c = 1.0587 \times 10^{-31} \text{ kg.m/s} \quad (17)$$

Moreover, the dark matter particle mean life time τ can be determined using Blank constant $\bar{h} = h / 2\pi = 6.58 \times 10^{-16} \text{ eV.s}$ such that

$$\tau = \frac{\bar{h}}{E} = \frac{6.58 \times 10^{-16} \text{ eV.s}}{1.972610^{-4} \text{ eV}} = 3.3357 \times 10^{-12} \text{ s} = 3.3357 \text{ ps} \quad (18)$$

Additionally, based on the mean life time τ , then one can calculate the frequency of dark matter

$$f = 1 / \tau = 0.29979 \times 10^{12} \text{ Hz} = 0.29979 \text{ THz} \quad (19)$$

Finally the virtual wave length of such dark matter particle would be

$$\lambda = \tau.c = 0.001 \text{ m} = 1 \text{ mm} \quad (20)$$

It can be concluded that it takes the dark matter particle 3.3357 ps to travel 1 mm. Meanwhile, it takes the light 3.3 ps to travel 1 mm.

4. Dark Matter and Particles Standard Model

As discussed before it has seen, the mass of the electron is much heavier than this candidate particle by 2.5796 billion

times, meanwhile, the proton weighs 4.7365 trillion (4.7365×10^{12}) dark matter particles. The atomic mass unit $\text{amu} = 0.93146 \text{ GeV}/c^2$. Now let us compare the mass of the dark matter particle to the standard value of (amu), leads to the conclusion that 4.7220 Trillion (4.7220×10^{12}) dark matter particles are required to construct 1 unity of atomic mass unit. In other words each dark matter particle weighs (2.1177×10^{-13}) amu.

A proton has a mass of approximately $938 \text{ MeV}/c^2$, of which the rest mass of its three valence quarks only contributes about $9.6 \text{ MeV}/c^2$; much of the remainder can be attributed to the gluons quantum chromodynamics binding energy (QCBE).

$$\begin{aligned} 1 \text{ Proton} &= 2u + 2d + \text{Gluon Energy} \\ &= 2 \times 2.4 \text{ MeV} + 4.8 \text{ MeV} + \text{QCBE} \quad (21) \\ &= 9.6 \text{ MeV} + \text{QCBE} \end{aligned}$$

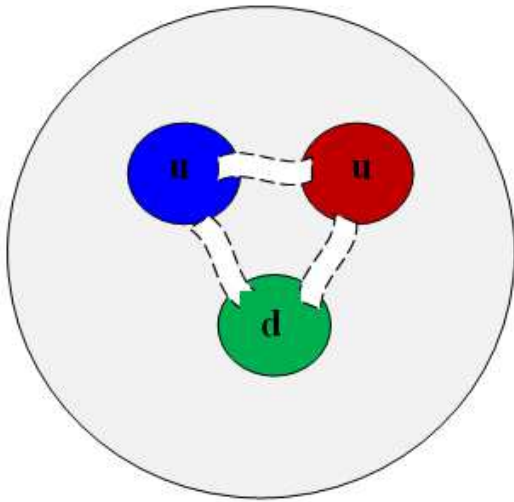


Figure 1. Schematics of the Structure of the Proton according to Standard Model.

Based on the standard model [36], each proton is composed of 2 up quarks and 1 down quark as shown in Figure 1. Meanwhile, Neutron is composed of 1 up quark and 2 down quarks as shown in Figure 2. It is desired now to compare the mass of the dark matter particle with the up quark (2.4 MeV), down quark (4.8 MeV), and the gluon (928.4 MeV), respectively. The comparison leads to the

$$\begin{aligned} m &= \rho V = \rho \left(\frac{4}{3} \pi r^3 \right) = \rho \left(\frac{4}{3} \pi (ct)^3 \right) \\ &= 9.9 \times 10^{-27} \left(\frac{4}{3} \pi (2.998 \times 10^8 \times 13.7 \times 10^9 \times 365.25 \times 24 \times 3600) \right)^3 \\ &= 9.0116 \times 10^{52} \text{ kg} \end{aligned} \quad (23)$$

The equivalent mass of the universe can be presented in an equivalent number of protons and dark matter particles as follows: 5.3878×10^{79} protons or 2.5519×10^{92} dark matter particles.

Based on the astronomical observation that the universe is

expanding at an accelerating rate, based on the CMB observation that the average temperature of the sky is 2.73 K and by the virtue of the ideal equation of state then it can be assumed that the expansion process is isothermal (constant temperature). It is possible now to express the equation of state

$$\begin{aligned} 1 \text{ Neutron} &= 1u + 2d + \text{Gluon Energy} \\ &= 2.4 \text{ MeV} + 2 \times 4.8 \text{ MeV} + \text{QCBE} \quad (22) \\ &= 12 \text{ MeV} + \text{QCBE} \end{aligned}$$

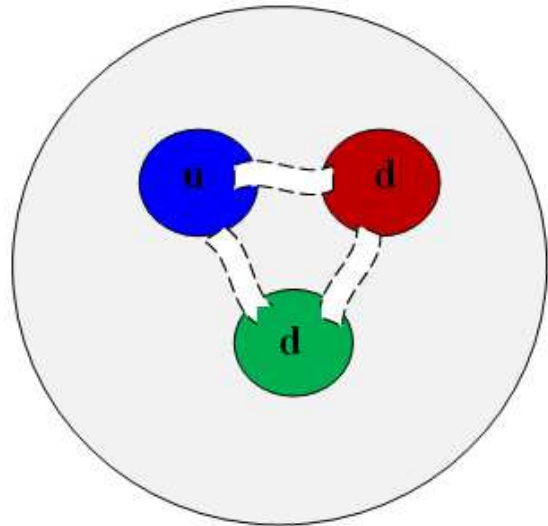


Figure 2. Schematics of the Structure of the Neutron to Standard Model.

5. Dark Energy and the Accelerated Expansion of the Universe

The equivalent mass of the universe can be estimated based on the estimated age of the universe and the speed of light. One of the most of the acceptable estimated value of the age of the universe is considered as 13.7 billion years. Assume that after the Big Bang the universe is expanding such that it has a radius equivalent to the distance has been traveled by the light. Accordingly, it is possible to estimate the mass of the universe as follows

expanding at an accelerating rate, based on the CMB observation that the average temperature of the sky is 2.73 K and by the virtue of the ideal equation of state then it can be assumed that the expansion process is isothermal (constant temperature). It is possible now to express the equation of state

as

$$P = NK_B \frac{T}{V} \quad (24)$$

In thermodynamics [2], the work involved when an ideal changes from state 1 to state 2 is simply

$$W_{1 \rightarrow 2} = \int_{V_1}^{V_2} P dV = \int_{V_1}^{V_2} NK_B \frac{T}{V} dV = NK_B T \int_{V_1}^{V_2} \frac{1}{V} dV = NK_B T \ln \frac{V_2}{V_1} \quad (25)$$

For an isothermal, reversible process, this integral equals the area under the relevant pressure-volume isotherm for an ideal gas. By convention, work is defined as the work the system does on its environment. As per Joule's Law, Internal energy is the function of absolute temperature. In isothermal process the temperature is constant. Hence, the internal energy is constant. Moreover, the net change in internal energy is zero.

Based on the ideal gas law governed by (2), $PV = mRT = E = \text{const.}$, it yields that

$$P = Nk_B T \times \frac{1}{V} \quad (26)$$

Since the universe is expanding with an homogenous CMB temperature of 2.73 K, then it is desired no to express the pressure to volume rate of change as follows:

$$dP / dV = d / dV (Nk_B T \times \frac{1}{V}) \quad (27)$$

$$dP / dV = -Nk_B T \times \frac{1}{V^2} \quad (28)$$

$$dP / dV = \text{const} \times -\frac{1}{V^2} \quad (29)$$

By the virtue of (29), it is concluded that the universe rate of change of pressure with respect of its volume is inversely proportional to the negative of squared volume $-1/V^2$ as shown in Figure 3. Furthermore, since the dark energy pressure is so tiny small $8.8981 \times 10^{-10} \text{ J/m}^3$ but not zero, then it yields that the universe volume is not infinite and flat. Remember that the estimated current universe volume is $(4/3)\pi(2.998 \times 10^8 \times 13.7 \times 10^9 \times 365.25 \times 24 \times 3600)^3$ which is equivalent to $9.1213 \times 10^{78} \text{ m}^3$. Hence, the current universe pressure to volume rate of change $-1.155 \times 10^{-88} \text{ N/m}^2 / \text{m}^3$.

6. The Generation of the Periodic Table Elements and Critical Temperature

The critical temperature at which one entity would be generated is found to be equal to 64.478 Tetra Kelvin as addressed earlier in Section 3. Interestingly, the calculated

critical temperature of the quark-gluon plasma is found to be proportional to the temperature generated by colliding heavy ions at the Relativistic Heavy Ion Collider (RHIC) and European Organization for Nuclear Research (CERN).

Recent analyses from the Relativistic Heavy Ion Collider (RHIC), a 2.4-mile-circumference (atom smasher) at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory, establish that collisions of gold ions traveling at nearly the speed of light have created matter at a temperature of about 4 Trillion degrees Celsius — the hottest temperature ever reached in a laboratory, about 250,000 times hotter than the center of the Sun [31-35]. This temperature, based upon measurements by the PHENIX collaboration at RHIC, is higher than the temperature needed to melt protons and neutrons into a plasma of quarks and gluons. These new temperature measurements, combined with other observations analyzed over nine years of operations by RHIC's four experimental collaborations — BRAHMS, PHENIX, PHOBOS, and STAR — indicate that RHIC's gold-gold collisions produce a freely flowing liquid composed of quarks and gluons. Such a substance, often referred to as quark-gluon plasma, or QGP, filled the universe a few microseconds after it came into existence 13.7 billion years ago. At RHIC, this liquid appears, and the quoted temperature is reached, in less time than it takes light to travel across a single proton.

The objective in this section is to determine the individual critical temperature of the quark-gluon plasma matter at which the elements of the periodic table are generated. The quark-gluon plasma (QGP) critical temperature of the elements of the periodic table groups and periods is calculated by the virtue of Equation (13):

$$T = \frac{\rho_E}{\rho_N K_B} = 6.4478 \times 10^{13} \frac{1}{\rho_N} \text{ K} = \frac{64.478}{\rho_N} \text{ TK} . \text{ Based on}$$

the results demonstrated in Novel Periodic Table displayed in Table 1 and Table 5 (Appendix 1), it can be seen that the highest critical temperature needed to generate quark-gluon plasma (QGP) from Hydrogen atom is 64 TK (5516 MeV), followed by 16.1 TK (1389 MeV) needed to generate QGP from Helium, ended by the 0.219 TK (18.9 MeV) to produce QGP from the last periodic undiscovered yet element. It is interesting to know that the critical temperatures at which QGP is generated out of Gold atom and Uranium atom are 0.327 TK (28.8 MeV) and 0.271 (23.4 MeV), respectively. The average QGP critical temperature of all natural elements is figured to be 1.627 TK (18.9 MeV).

Based on these obtained primary results of QGP critical temperatures, it is interesting to test the QGP critical temperature trend of the elements of the periodic table groups and periods. It is figured out that the overall trend is of negative power regression $y = 40.075x^{-1.099} \text{ (TK)}$ in Temperature scale and $y = 3455.1x^{-1.099} \text{ (MeV)}$ in energy scale as shown in Figure 3 and 4, respectively. This hints how was the trend at which the elements were created after the Big Bang. The QGP critical temperature is decreasing dramatically going down from Hydrogen,

through Helium and ending by the Transition metals at Period 7.

Table 1. Novel Projected Periodic Table of Quark-Gluon Plasma Critical Temperature of Natural Elements.

Group	1	2	3	4	5	6	7	8	9
Period									
1	1 H 64.0								
2	3 Li 9.29	4 Be 7.15							
3	11 Na 2.80	12 Mg 2.65							
4	19 K 1.65	20 Ca 1.60	21 Sc 1.434	22 Ti 1.35	23 V 1.27	24 Cr 1.24	25 Mn 1.17	26 Fe 1.15	27 Co 1.09
5	37 Rb 0.754	38 Sr 0.736	39 Y 0.725	40 Zr 0.707	41 Nb 0.694	42 Mo 0.672	43 Tc 0.658	44 Ru 0.638	45 Rh 0.627
6	55 Cs 0.485	56 Ba 0.470	*	72 Hf 0.361	73 Ta 0.356	74 W 0.350	75 Re 0.346	76 Os 0.339	77 Ir 0.335
7	87 Fr 0.289	88 Ra 0.285	**	104 Rf 0.241	105 Db 0.241	106 Sg 0.238	107 Bh 0.237	108 Hs 0.239	109 Mt 0.234

Table 1. continue.

Group	10	11	12	13	14	15	16	17	18						
Period															
1									2 He 16.1						
2				5 B 5.97	6 C 5.37	7 N 4.60	8 O 4.03	9 F 3.39	10 Ne 3.20						
3				13 Al 2.39	14 Si 2.30	15 P 2.08	16 S 2.01	17 Cl 1.82	18 Ar 1.61						
4	28 Ni 1.10	29 Cu 1.01	30 Zn 0.986	31 Ga 0.924	32 Ge 0.887	33 As 0.860	34 Se 0.816	35 Br 0.807	36 Kr 0.769						
5	46 Pd 0.606	47 Ag 0.598	48 Cd 0.574	49 In 0.562	50 Sn 0.543	51 Sb 0.530	52 Te 0.505	53 I 0.508	54 Xe 0.491						
6	78 Pt 0.331	79 Au 0.327	80 Hg 0.321	81 Tl 0.315	82 Pb 0.311	83 Bi 0.309	84 Po 0.309	85 At 0.307	86 Rn 0.290						
7	110 Ds 0.229	111 Rg 0.226	112 Cn 0.226	113 Uut 0.227	114 Fl 0.223	115 Uup 0.224	116 Lv 0.220	117 Uus 0.219	118 Uuo 0.219						
Lanthanide	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Series*	0.464	0.460	0.457	0.447	0.445	0.429	0.424	0.410	0.406	0.397	0.391	0.385	0.382	0.373	0.369
Actinide	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr
Series**	0.284	0.278	0.279	0.271	0.272	0.264	0.265	0.261	0.261	0.257	0.255	0.250	0.250	0.249	0.246

Alkali metals	Lanthanides
Alkaline earth metals	Actinides
Transition metals	Nonmetals
Post-transition metals	Halogens
Metalloid	Noble gases

1	Atomic Number
H	Symbol
64.0	Quark-Gluon Critical Temperature (TK)

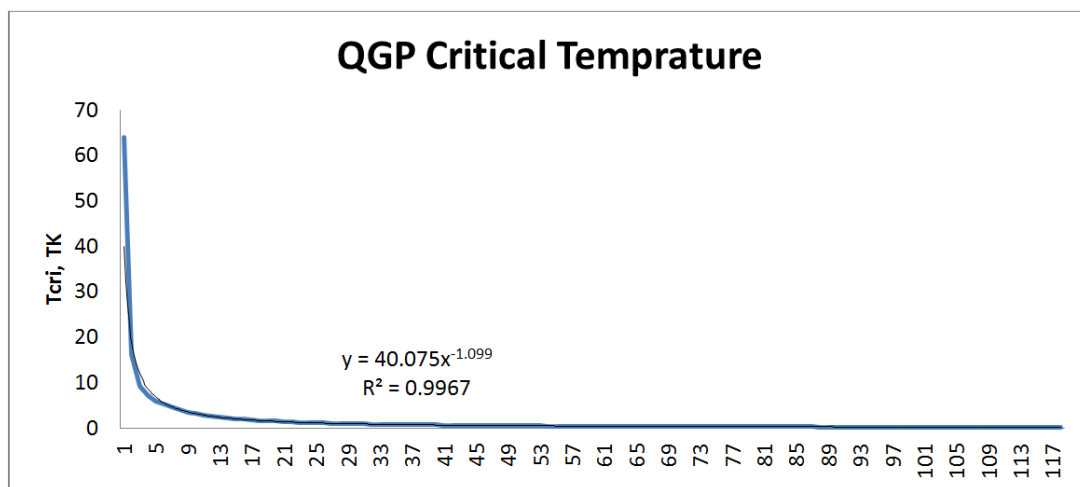


Figure 3. QGP Critical Temperature for Natural Elements of the Periodic Table.

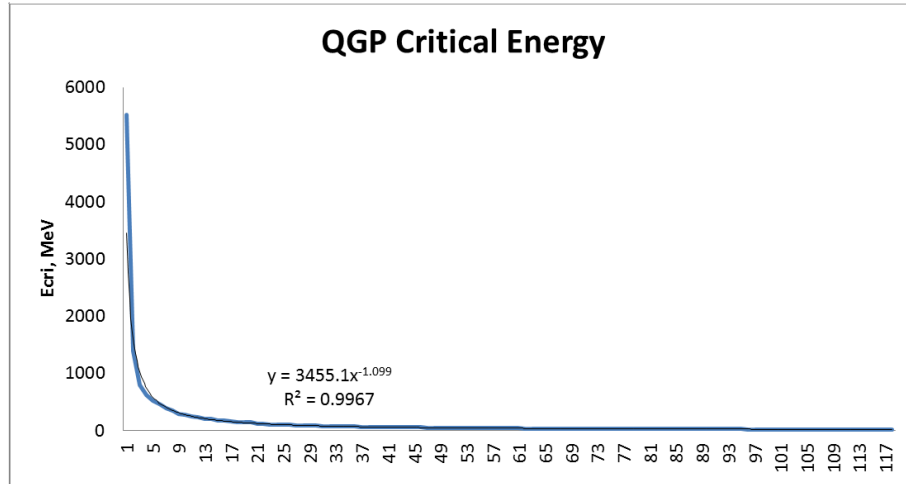
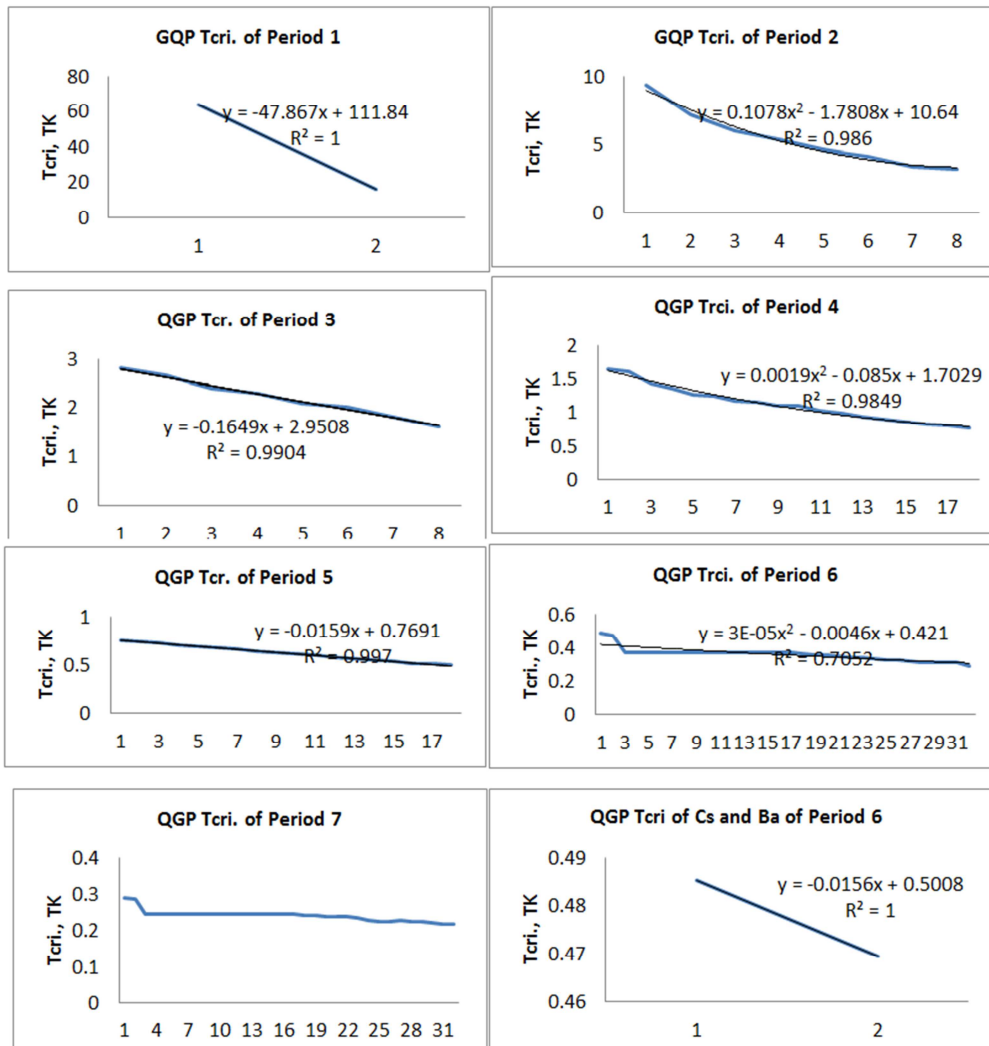


Figure 4. QGP Critical Energy for Natural Elements of the Periodic Table.

Let us examine the QGP critical temperature of the periods and the groups separately. The critical temperature of periods is found to have either linear trend with negative slope or quadratic decreasing trend. The first period takes the linear form, followed by a quadratic form for the second period, followed by a linear trend for the third period, followed by quadratic form for the fourth period, and then followed by a

linear trend for all successive periods fifth sixth and the seventh. Please refer to Table 2 and sub-Figures 5. It noticed that the negative slope is increasing by going down from the top period to the bottom period from slope -47.867 to -0.00038. The quadratic coefficient is also decreasing from 0.1078 in period 2 to 0.0019 in period 4.



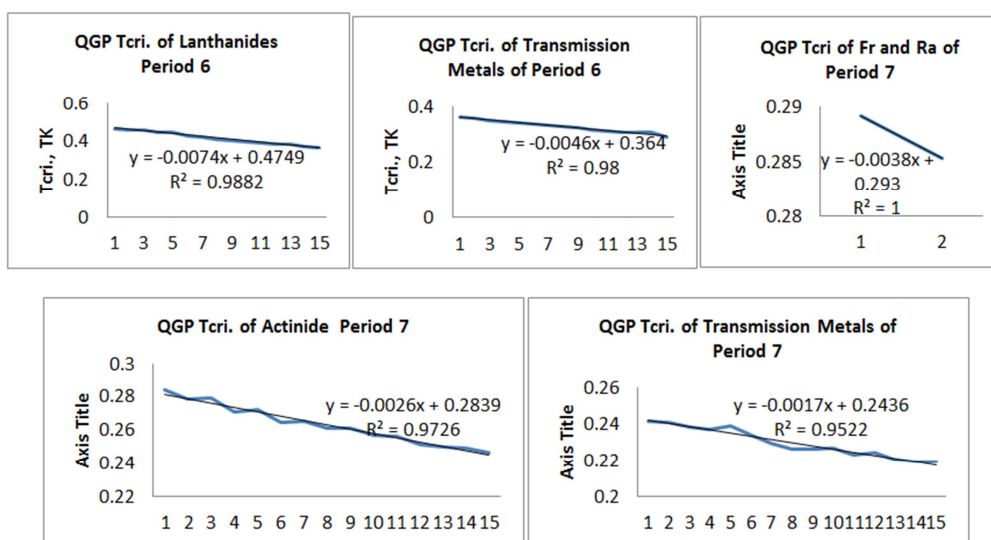


Figure 5. The Regression Trend of QGP Critical Temperature for Periods of the Periodic Table.

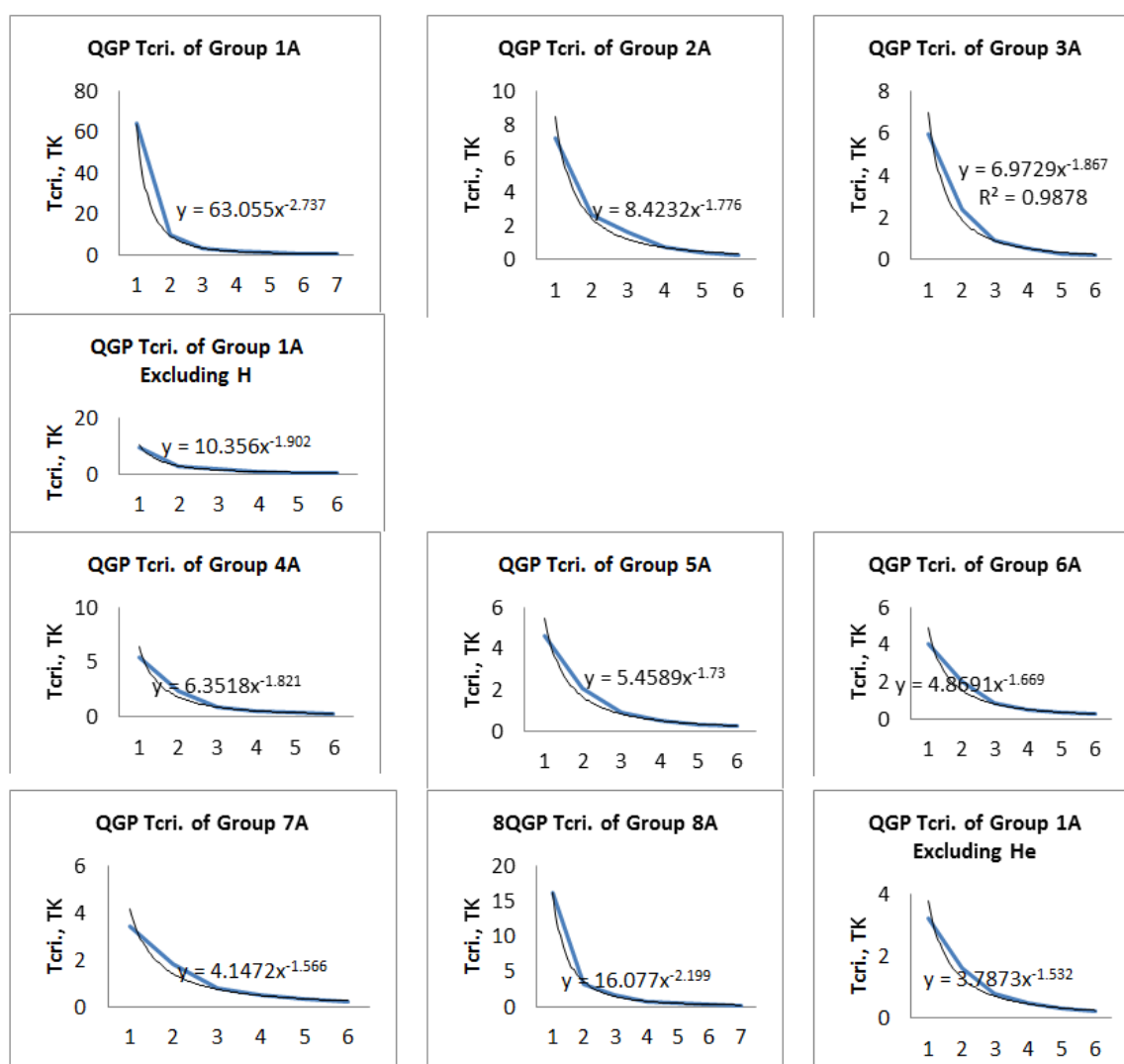


Figure 6. The Regression Trend of QGP Critical Temperature for Groups A of the Periodic Table.

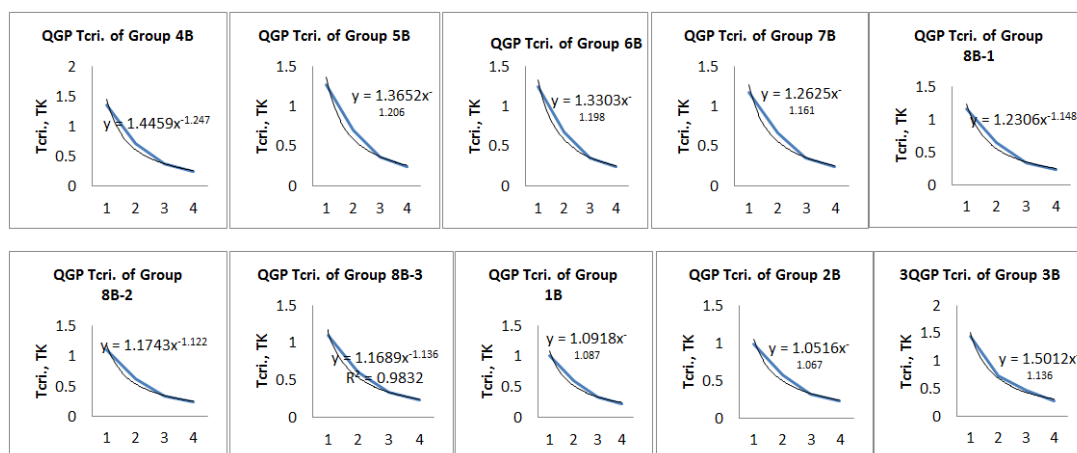


Figure 7. The Regression Trend of QGP Critical Temperature for Groups B of the Periodic Table.

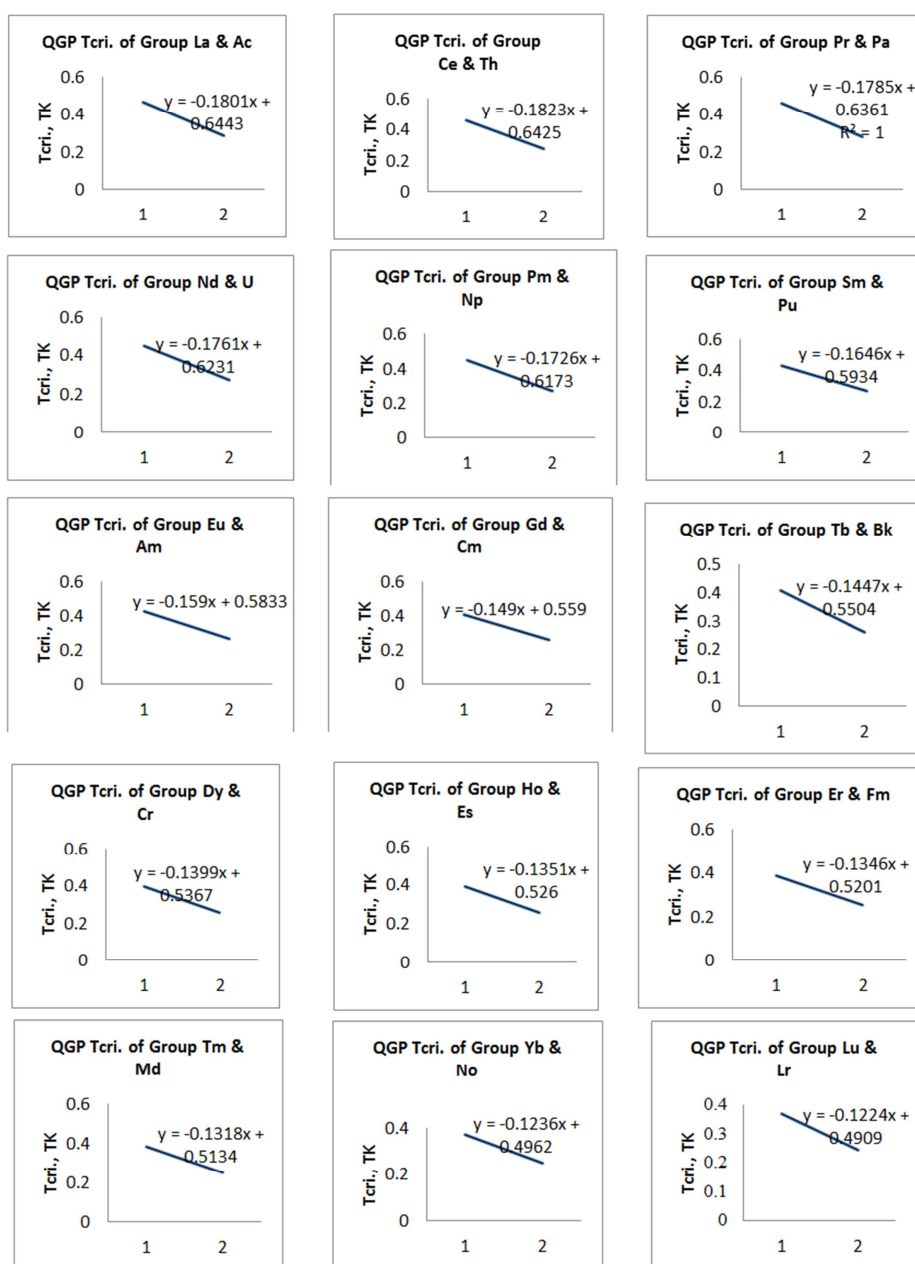


Figure 8. The Regression Trend of QGP Critical Temperature for the Lanthanides and Actinides of the Periodic Table.

Table 2. The Regression Trend of QGP Critical Temperature for Periods of the Periodic Table.

Period	Equation	R ²
Period 1	$y = -47.867x + 111.84$	1
Period 2	$y = 0.1078x^2 - 1.7808x + 10.64$	0.986
Period 3	$y = -0.1649x + 2.9508$	0.9904
Period 4	$y = 0.0019x^2 - 0.085x + 1.7029$	0.9849
Period 5	$y = -0.0159x + 0.7691$	0.997
Period 6	$y = -0.0156x + 0.5008$; $y = -0.0074x + 0.4749$; $y = -0.0046x + 0.364$	1; 0.9982; 0.98
Period 7	$y = -0.0038x + 0.293$; $y = -0.0026x + 0.2839$; $y = -0.0017x + 0.2436$;	1; 0.9726; 0.9552

On the other hand, let us now examine the QGP critical temperature of the groups. The critical temperature of groups is found to have negative power aggression trend. It is found out that both the power coefficient and negative exponent are decreasing as we go from left side of the groups A to the right side groups A. Similarly, groups B are showing a QGP decreasing QGP critical temperature pattern. Please refer to Table 3 and sub-Figures 6, sub-Figures 7. It noticed that the negative slope is increasing by going down from the top Period to the bottom Period. For example Group 1A shows a power trend of $y = 63.055x^{-2.737}$ (TK) (or $y = 10.356x^{-1.902}$ (TK) * excluding H), and ends with $y = 16.077x^{-2.199}$ (TK)

(or $y = 3.7873x^{-1.532}$ (TK) Excluding He) as displayed in Figures 6. Likely, Groups B (starting with 4B, 5B, 6B, 7B, 8B1, 8B2, 8B3, 1B and 2B) demonstrate negative power regression starting with $y = 1.4459x^{-1.247}$ and ending with $y = 1.0516x^{-1.067}$ (TK). The exception to this pattern is Group 3B which shows linearly decreasing trend beginning with $y = 1.5012x^{-1.136}$ (TK) and terminating with behavior $y = -0.1224x + 0.4909$. The QGP Critical Temperatures of Lanthanide and Actinide Series are shown in sub-Figures 8. The pattern demonstrates a decreasing linear regression trend.

Table 3. The Regression Trend of QGP Critical Temperature for the Groups of the Periodic Table.

Group	Equation	R ²
Group 1A	$y = 63.055x^{-2.737}$	$R^2 = 0.9981$
	$y = 10.356x^{-1.902}$ * * (Excluding H)	$R^2 = 0.987$ *
Group 2A	$y = 8.4232x^{-1.776}$	$R^2 = 0.9771$
Group 3A	$y = 6.9729x^{-1.867}$	$R^2 = 0.9878$
Group 4A	$y = 6.3518x^{-1.821}$	$R^2 = 0.9854$
Group 5A	$y = 5.4589x^{-1.73}$	$R^2 = 0.9838$
Group 6A	$y = 4.8691x^{-1.669}$	$R^2 = 0.979$
Group 7A	$y = 4.1472x^{-1.566}$	$R^2 = 0.9737$
Group 8A	$y = 3.7873x^{-1.532}$ (Excluding He)	$R^2 = 0.9978$
	$y = 16.077x^{-2.199}$	$R^2 = 0.9794$ **
Group 3B	$y = 1.5012x^{-1.136}$	$R^2 = 0.9864$
	$y = -0.1801x + 0.6443$ (Has been calculated with 3B)	
	$y = -0.1823x + 0.6425$	
	$y = -0.1785x + 0.6361$	
	$y = -0.1761x + 0.6231$	
	$y = -0.1726x + 0.6173$	
	$y = -0.1646x + 0.5934$	
	$y = -0.159x + 0.5833$	
	$y = -0.149x + 0.559$	
	$y = -0.1447x + 0.5504$	
	$y = -0.1399x + 0.5367$	
	$y = -0.1351x + 0.526$	
	$y = -0.1346x + 0.5201$	
	$y = -0.1318x + 0.5134$	
	$y = -0.1236x + 0.4962$	
	$y = -0.1224x + 0.4909$	
Group 4B	$y = 1.4459x^{-1.247}$	$R^2 = 0.9819$
Group 5B	$y = 1.3652x^{-1.206}$	$R^2 = 0.9779$
Group 6B	$y = 1.3303x^{-1.198}$	$R^2 = 0.9807$
Group 7B	$y = 1.2625x^{-1.161}$	$R^2 = 0.9779$
Group 8B1	$y = 1.2306x^{-1.148}$	$R^2 = 0.9819$
Group 8B2	$y = 1.1743x^{-1.122}$	$R^2 = 0.9776$
Group 8B3	$y = 1.1689x^{-1.136}$	$R^2 = 0.9832$
Group 1B	$y = 1.0883x^{-1.077}$	$R^2 = 0.9763$
Group 2B	$y = 1.0516x^{-1.067}$	$R^2 = 0.9799$

7. Utilization of Qaurk-Gulon Plasma Energy and its Pahse Diagram: A Novel Millennium Power Plant

It is estimated that the Hadron Epoch covers the time from 10^{-6} seconds to 1 second after the Big Bang [27]. The temperature during this epoch is estimated to decrease from 10^{13} K to 10^{10} K. At 10^{-5} seconds, the temperature of the Universe was approximately 10^{12} K. at which quarks combine to form protons and neutrons. Astrophysics predicts that Fermi melting point of quarks into quark-gluon plasma ($0.5\text{--}1.2 \times 10^{12}$ K) or higher. The results of this proposed analysis agree with such predictions. The phase diagram [32] of the quark-gluon plasma is a diagram at which the state of matter-energy. A new QGP phase diagram depicts the Hardon Epoch is proposed in Figure 9. The QGP phase

diagram presents a critical point that separates the two phases: the hadron gas in which quarks are confined, and the quark-gluon plasma (QGP).

Experimental results on relative abundances of various hadron species created in gold-gold collisions at RHIC and their comparison with particle abundances realized in a simple hadron resonance gas (HRG) suggest that the transition back to ordinary hadrons, the so-called chemical freeze out, occurs at temperatures of about (160-170) MeV [42]. Whether this freeze-out temperature is in any way related to the transition temperature in QCD is an important question that currently is studied extensively in large scale computer simulations. The simulations of the RBC-Bielefeld Collaboration performed on the QCDOC and apeNEXT computers hint at a larger transition temperature of about 190 MeV.

1 H - Hydrogen - [1.007 84; 1.008 11]	5515.874746
2 He - Helium - 4.002 602(2)	1388.876337
3 Li - Lithium - [6.938; 6.997]	801.2567316
4 Be - Beryllium - 9.012 1831(5)	616.8448989
5 B - Boron - [10.806; 10.821]	514.4474555
6 C - Carbon - [12.0096; 12.0116]	462.889622
7 N - Nitrogen - [14.006 43; 14.007 28]	396.8976537
8 O - Oxygen - [15.999 03; 15.999 77]	347.4660154
9 F - Fluorine - 18.998 403 163(6)	292.6098134
10 Ne - Neon - 20.1797(6)	275.4799464
11 Na - Sodium - 22.989 769 28(2)	241.8083947
12 Mg - Magnesium - [24.304, 24.307]	228.7326861
13 Al - Aluminium - 26.981 5385(7)	206.0341811
14 Si - Silicon - [28.084; 28.086]	197.9461332
15 P - Phosphorus - 30.973 761 998(5)	179.4783341
16 S - Sulfur - [32.059; 32.076]	173.4027638
17 Cl - Chlorine - [35.446; 35.457]	156.8334707
18 Ar - Argon - 39.948(1)	139.1585383

116 Lv - Livermorium - <293>	18.97310309
117 Uus- <294>	18.90856872
118 Uuo - Ununoctium - <294>	18.90856872

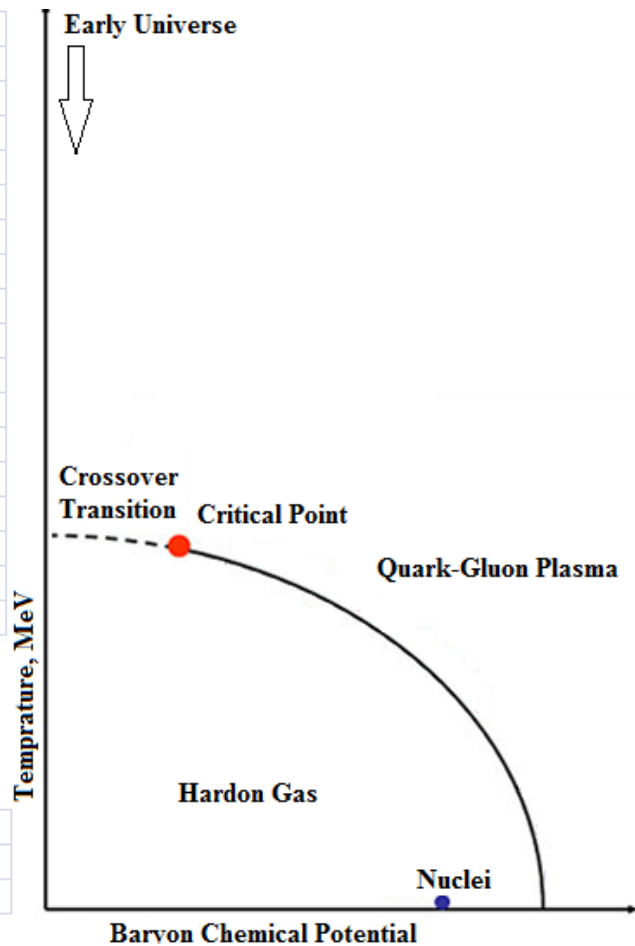


Figure 9. The QGP Phase Diagram and Associated Critical Temperature.

Based on this research analysis, it is found out that dark matter/dark energy behaves like an ideal fluid and there density are affected by the space temperature. Moreover, utilization of its energy can be achieved at high temperatures such as Fermi melting point. Hence ρ_N is unity when the temperature T is equal to 64×10^{12} K, then this temperature

value is called the critical temperature. In other words at this temperature the $\rho_N = 12.81 \times 10^{12}$ entities / m^3 of dark matter particles are unified (melted) to form quark-gluon plasma which work as the basic blocks of matter.

CMB and WMAP confirm that the density of dark matter/dark energy is uniform, homogeneous and constant

through the universe. Since the density is at the same order of the proton-neutron, then it is very possible that dark energy/dark matter is converted into quarks at this QGP critical temperature. Similar to Relativistic Heavy Ion Collider (RHIC), it is proposed here to generate quark-gluon plasma and utilize its associated energy. Based on Table 5 (Appendix 1), it can be seen that the generated energy QGP is ranging from 5516 MeV associated with Hydrogen, 207 MeV and 197 MeV associated with Lead and Gold atoms, respectively.

Recent analyses from the Relativistic Heavy Ion Collider (RHIC), a 2.4-mile-circumference (atom smasher) at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory, establish that collisions of gold ions traveling at nearly the speed of light have created matter at a temperature of about 4 trillion degrees Celsius — the hottest temperature ever reached in a laboratory, about 250,000 times hotter than the center of the Sun [31-35]. This temperature, based upon measurements by the PHENIX collaboration at RHIC, is higher than the temperature needed to melt protons and neutrons into a plasma of quarks and gluons. These new

temperature measurements, combined with other observations analyzed over nine years of operations by RHIC's four experimental collaborations — BRAHMS, PHENIX, PHOBOS, and STAR — indicate that RHIC's gold-gold collisions produce a freely flowing liquid composed of quarks and gluons. Such a substance, often referred to as quark-gluon plasma, or QGP, filled the universe a few microseconds after it came into existence 13.7 billion years ago.

A novel Quark-Gluon Plasma power generation reactor is proposed in this work as displayed in Figure 10. It basically utilizes the output temperatures to heat up cold water and converts into a steam. The pressurized steam will generate a high mechanical rotational at the turbines and then high induced electrical power at the electrical generators. It is remarkable to note here that the outcome energy of the QGP range [5516 to 18.9 MeV] would be much higher compared with the nuclear fission which generates 0.8 MeV per atomic unit and 3.5 MeV per atomic unit that can be produced from the nuclear fusion as tabulated in Table 4.

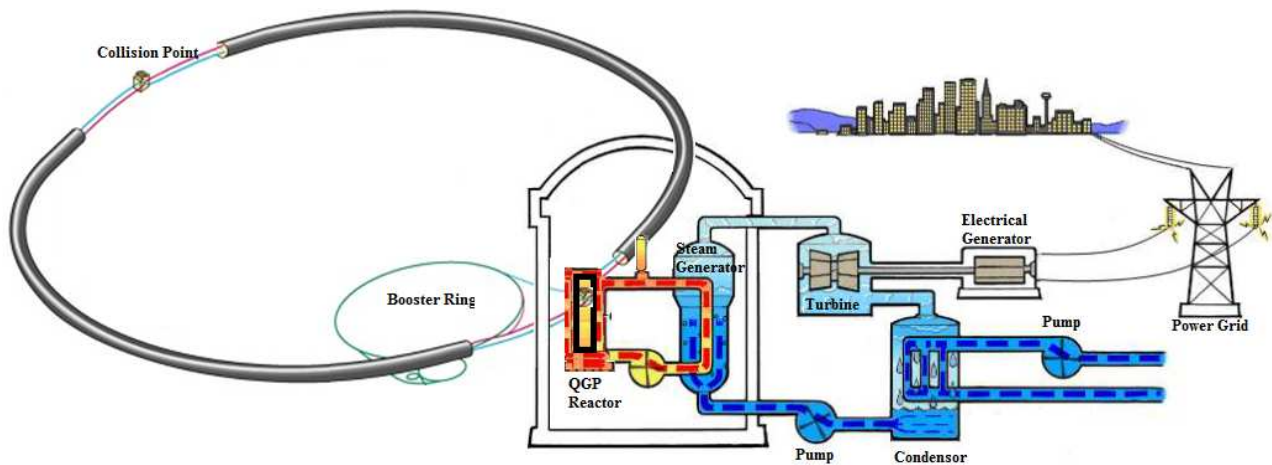


Figure 10. The Novel QGP Power Generation Plant.

Table 4. Comparison of QGP Energy Outcome with other Energy Sources.

No.	Energy Source	Output Energy, MeV
1	QGP of Hydrogen	5515/atomic unit
2	QGP of Helium	1389/atomic unit
3	QGP of Lead	207/atomic unit
4	QGP of Gold	197/atomic unit
5	Nuclear Fission	0.8 /atomic unit
6	Nuclear Fusion	3.5/atomic unit
7	Hydrogen Ion annihilation	938 /atomic unit

8. Concluisions

In this work, a new physical interpretation of the state of matter of the quark-gluon as the most fundamental building blocks in nature. Such a model is derived based on the assumption that dark matter and dark energy behave as a perfect ideal fluid at extremely high temperature. By the virtue of Boltzmann constant of the ideal gas law and NASA's Cosmic Microwave Background Explorer (CMB) which estimated that the space has an average temperature

close to 2.7251 Kelvin, then the equivalent mass-energy of the fundamental particle of the dark matter/dark energy is determined.

The average universe mass density of $9.91 \times 10^{-30} \text{ g/cm}^3$ is equivalent to only 5.9 protons per cubic meter or $8.8981 \times 10^{-10} \text{ J/m}^3 = 5.5302 \times 10^9 \text{ eV/m}^3 = 5.5302 \text{ GeV/m}^3$. The temperature at which one entity would be generated called in this work as the critical temperature and equals to 64×10^{12} Kelvin. The calculated critical temperature at which 5.9 protons per cubic meter were produced is found to be $10.929 \times 10^{12} \text{ K}$. The equivalent mass of dark matter particle, its mean life time and frequency is further determined.

Based on the standard model, the gluon energy that bonds quarks of protons and the quarks of the neutron is investigated. Each proton quarks are tied by 928.4 MeV gluon energy, Meanwhile, Each proton quarks are tied by 926 MeV gluon energy.

Moreover, this research has investigated the expansion of

the universe based on the thermodynamics isothermal concept. it is concluded that the universe rate of change of pressure with respect of its volume is inversely proportional to the negative of squared volume $-1/V^2$. Furthermore, since the dark energy pressure is so tiny small $8.8981 \times 10^{-10} \text{ J/m}^3$ but not zero, then it yields that the universe volume is not infinite and flat with current universe pressure to volume rate of change $-1.155 \times 10^{-88} \text{ N/m}^2 / \text{m}^3$.

Furthermore, the individual critical temperature of the quark-gluon plasma matter at which the elements of the periodic table are generated is determined. Based on the results, a novel Periodic Table is introduced. It can be seen that the highest critical temperature needed to generate quark-gluon plasma (QGP) from Hydrogen atom is 64 TK (5516 MeV), followed by 16.1 TK (1389 MeV) needed to generate QGP from Helium, ended by the 0.219 TK (18.9 MeV) to produce QGP from the last periodic undiscovered yet element. It is interesting to know that the critical temperatures at which QGP is generated out of Gold atom and Uranium atom are 0.327 TK (28.8 MeV) and 0.271 (23.4 MeV), respectively. The average QGP critical temperature of all natural elements is figured to be 1.627 TK (18.9 MeV).

Additionally, the QGP critical temperature trend of the elements of the Periodic Table Groups and Periods is then tested. It is figured out that the overall trend is of negative power regression $y = 40.07x^{-1.099}$ (TK) in Temperature scale and $y = 3455.1x^{-1.099}$ (MeV) in energy scale. This hints how was the trend at which the elements were created after the Big Bang. The QGP critical temperature is decreasing dramatically going down from Hydrogen, through Helium and ending by the Transition metals at Period 7. Then, the QGP critical temperatures of the periods and the groups are examined separately. The critical temperature of periods is found to have either linear trend with negative slope or quadratic decreasing trend. The first period takes the linear form, followed by a quadratic form for the second period, followed by a linear trend for the third period, followed by quadratic form for the fourth period, and then followed by a linear trend for all successive periods fifth sixth and the seventh. It noticed that the negative slope is increasing by

going down from the top period to the bottom period from slope -47.867 to -0.00038. The quadratic coefficient is also decreasing from 0.1078 in period 2 to 0.0019 in period 4.

On the other hand, the QGP critical temperatures of the groups are investigated. The critical temperature of groups is found to have negative power aggression trend. It is found out that both the power coefficient and negative exponent are decreasing as we go from left side of the groups A to the right side groups A. Similarly, groups B are showing a QGP decreasing QGP critical temperature pattern. It noticed that the negative slope is increasing by going down from the top period to the bottom period. For example Group 1A shows a power trend of $y = 63.055x^{-2.737}$ (TK) (or $y = 10.356x^{-1.902}$ (TK) * excluding H), and ends with $y = 16.077x^{-2.199}$ (TK) (or $y = 3.7873x^{-1.532}$ (TK) Excluding He). Likely, Groups B (starting with 4B, 5B, 6B, 7B, 8B1, 8B2, 8B3, 1B and 2B) demonstrate negative power regression starting with $y = 1.4459x^{-1.247}$ and ending with $y = 1.0516x^{-1.067}$ (TK). The exception to this pattern is Group 3B which shows linearly decreasing trend beginning with $y = 1.5012x^{-1.136}$ (TK) and terminating with behavior $y = -0.1224x + 0.4909$ (TK). The QGP Critical Temperatures of Lanthanide and Actinide Series are tested as well. The pattern demonstrates a decreasing linear regression trend.

A new QGP phase diagram depicts the Hardon Epoch is proposed in this work. The QGP phase diagram presents a critical point that separates the two phases: the hadron gas in which quarks are confined, and the quark-gluon plasma (QGP). Finally, a novel Quark-Gluon Plasma power generation reactor is proposed. It basically utilizes the output temperatures to heat up cold water and converts into a steam. The pressurized steam will generate a high mechanical rotational at the turbines and then high induced electrical power at the electrical generators. It is remarkable to note here that the outcome energy of the QGP range [5516 to 18.9 MeV] would be much higher compared with the nuclear fission which generates 0.8 MeV per atomic unit and 3.5 MeV per atomic unit that can be produced from the nuclear fusion. Future work will elaborate more on this QCD power plant analysis and design.

Appendix 1

Table 5. Projected Values of Quark-Gluon Plasma Critical Temperature of Natural Elements.

Element	AW (Atomic Weight)	Equivalent Energy (MeV)	Critical Temperature (TK)
1 H - Hydrogen - [1.007 84; 1.008 11]	1.00784	5515.874746	63.97642483
2 He - Helium - 4.002 602(2)	4.002602	1388.876337	16.10902108
3 Li - Lithium - [6.938; 6.997]	6.938	801.2567316	9.293456327
4 Be - Beryllium - 9.012 1831(5)	9.01218315	616.8448989	7.154537244
5 B - Boron - [10.806; 10.821]	10.806	514.4474555	5.966870257
6 C - Carbon - [12.0096; 12.0116]	12.0096	462.889622	5.368871569
7 N - Nitrogen - [14.006 43; 14.007 28]	14.00643	396.8976537	4.603457126
8 O - Oxygen - [15.999 03; 15.999 77]	15.99903	347.4660154	4.030119326
9 F - Fluorine - 18.998 403 163(6)	18.99840316	292.6098134	3.393864181
10 Ne - Neon - 20.1797(6)	20.17976	275.4799464	3.195181707
11 Na - Sodium - 22.989 769 28(2)	22.98976928	241.8083947	2.804638846
12 Mg - Magnesium - [24.304, 24.307]	24.304	228.7326861	2.652978934
13 Al - Aluminium - 26.981 5385(7)	26.98153857	206.0341811	2.389708053

Element	AW (Atomic Weight)	Equivalent Energy (MeV)	Critical Temperature (TK)
14 Si - Silicon - [28.084; 28.086]	28.084	197.9461332	2.29589802
15 P - Phosphorus - 30.973 761 998(5)	30.973762	179.4783341	2.081697406
16 S - Sulfur - [32.059; 32.076]	32.059	173.4027638	2.011229296
17 Cl - Chlorine - [35.446; 35.457]	35.446	156.8334707	1.819048694
18 Ar - Argon - 39.948(1)	39.9481	139.1585383	1.614044222
19 K - Potassium - 39.0983(1)	39.09831	142.1831073	1.649124988
20 Ca - Calcium - 40.078(4)	40.0784	138.7061161	1.608796758
21 Sc - Scandium - 44.955 908(5)	44.9559085	123.657143	1.434249738
22 Ti - Titanium - 47.867(1)	47.8671	116.1365365	1.347021232
23 V - Vanadium - 50.9415(1)	50.94151	109.1274916	1.265726124
24 Cr - Chromium - 51.9961(6)	51.99616	106.9140337	1.240053112
25 Mn - Manganese - 54.938 044(3)	54.9380443	101.1888806	1.17364935
26 Fe - Iron - 55.845(2)	55.8452	99.54515704	1.154584458
27 Co - Cobalt - 58.933 194(4)	58.9331944	94.32916815	1.09408629
28 Ni - Nickel 58.6934(4)	58.69344	94.71448946	1.098555477
29 Cu - Copper - 63.546(3)	63.5463	87.48139867	1.014661751
30 Zn - Zinc - 65.38(2)	65.382	85.02522413	0.986173565
31 Ga - Gallium - 69.723(1)	69.7231	79.7313832	0.924772421
32 Ge - Germanium - 72.630(8)	72.6308	76.53941859	0.887750101
33 As - Arsenic - 74.921 595(6)	74.9215956	74.19915659	0.860606338
34 Se - Selenium - 78.971(8)	78.9718	70.39372541	0.816468663
35 Br - Bromine - [79.901; 79.907]	79.901	69.57508922	0.80697363
36 Kr - Krypton - 83.798(2)	83.7982	66.33936295	0.769443735
37 Rb - Rubidium - 85.4678(3)	85.46783	65.04341112	0.754412508
38 Sr - Strontium - 87.62(1)	87.621	63.44505546	0.73587382
39 Y - Yttrium - 88.905 84(2)	88.905842	62.52816552	0.725239181
40 Zr - Zirconium - 91.224(2)	91.2242	60.93908419	0.706808062
41 Nb - Niobium - 92.906 37(2)	92.906372	59.83571508	0.694010525
42 Mo - Molybdenum - 95.95(1)	95.951	57.93706375	0.671988828
43 Tc - Technetium - <98>	98	56.72570616	0.657938776
44 Ru - Ruthenium - 101.07(2)	101.072	55.00157515	0.63794127
45 Rh - Rhodium - 102.905 50(2)	102.905502	54.02159356	0.626574855
46 Pd - Palladium - 106.42(1)	106.421	52.237051	0.60587666
47 Ag - Silver - 107.8682(2)	107.86822	51.53620968	0.597747882
48 Cd - Cadmium - 112.414(4)	112.4144	49.45202042	0.573574204
49 In - Indium - 114.818(1)	114.8181	48.41674966	0.561566513
50 Sn - Tin - 118.710(7)	118.7107	46.82913338	0.543152386
51 Sb - Antimony - 121.760(1)	121.7601	45.65632916	0.529549499
52 Te - Tellurium - 127.60(3)	127.603	43.56574065	0.505301599
53 I - Iodine - 126.904 47(3)	126.904473	43.80554186	0.508082958
54 Xe - Xenon - 131.293(6)	131.2936	42.34112862	0.491097814
55 Cs - Cesium - 132.905 451 96(6)	132.905452	41.82762349	0.485141874
56 Ba - Barium - 137.327(7)	137.3277	40.48068382	0.469519259
57 La - Lanthanum - 138.905 47(7)	138.905477	40.0208784	0.46418616
58 Ce - Cerium - 140.116(1)	140.1161	39.67509233	0.460175526
59 Pr - Praseodymium - 140.907 66(2)	140.907662	39.45221378	0.457590447
60 Nd - Neodymium - 144.242(3)	144.2423	38.54014533	0.44701173
61 Pm - Promethium - <145>	145	38.33875313	0.444675862
62 Sm - Samarium - 150.36(2)	150.362	36.97156997	0.428818451
63 Eu - Europium - 151.964(1)	151.9641	36.5817927	0.424297581
64 Gd - Gadolinium - 157.25(3)	157.253	35.35143497	0.410027154
65 Tb - Terbium - 158.925 35(2)	158.925352	34.97943616	0.405712488
66 Dy - Dysprosium - 162.500(1)	162.5001	34.20994328	0.396787448
67 Ho - Holmium - 164.930 33(2)	164.930332	33.70586318	0.390940825
68 Er - Erbium - 167.259(3)	167.2593	33.23653276	0.385497249
69 Tm - Thulium - 168.934 22(2)	168.934222	32.9070045	0.381675182
70 Yb - Ytterbium - 173.054(5)	173.0545	32.12351718	0.372587826
71 Lu - Lutetium - 174.9668(1)	174.96681	31.77242132	0.368515606
72 Hf - Hafnium - 178.49(2)	178.492	31.1449208	0.361237478
73 Ta - Tantalum - 180.947 88(2)	180.947882	30.72221207	0.356334649
74 W - Tungsten - 183.84(1)	183.841	30.23873458	0.350726987
75 Re - Rhenium - 186.207(1)	186.2071	29.85449644	0.346270362

Element	AW (Atomic Weight)	Equivalent Energy (MeV)	Critical Temperature (TK)
76 Os - Osmium - 190.23(3)	190.233	29.22268589	0.338942245
77 Ir - Iridium - 192.217(3)	192.2173	28.92101389	0.335443272
78 Pt - Platinum - 195.084(9)	195.0849	28.49589694	0.33051251
79 Au - Gold - 196.966 569(5)	196.9665695	28.22366871	0.327355044
80 Hg - Mercury - 200.592(3)	200.5923	27.71352242	0.321438061
81 Tl - Thallium - [204.382; 204.385]	204.382	27.19965165	0.31547788
82 Pb - Lead - 207.2(1)	207.21	26.82843108	0.311172241
83 Bi - Bismuth - 208.980 40(1)	208.980401	26.601151	0.30853611
84 Po - Polonium - <209>	209	26.59865648	0.308507177
85 At - Astatine - <210>	210	26.47199621	0.307038095
86 Rn - Radon - <222>	222	25.0410775	0.290441441
87 Fr - Francium - <223>	223	24.92878567	0.289139013
88 Ra - Radium - <226>	226	24.59787258	0.285300885
89 Ac - Actinium - <227>	227	24.48951191	0.284044053
90 Th - Thorium - 232.037 7(4)	232.03774	23.95782343	0.277877211
91 Pa - Protactinium - 231.035 88(2)	231.035882	24.06171351	0.27908219
92 U - Uranium - 238.028 91(3)	238.028913	23.3548065	0.270883059
93 Np - Neptunium - <237>	237	23.45619917	0.272059072
94 Pu - Plutonium - <244>	244	22.78327543	0.264254098
95 Am - Americium - <243>	243	22.87703376	0.265341564
96 Cm - Curium - <247>	247	22.50655548	0.261044534
97 Bk - Berkelium - <247>	247	22.50655548	0.261044534
98 Cf - Californium - <251>	251	22.14788528	0.256884462
99 Es - Einsteinium - <252>	252	22.05999684	0.255865079
100 Fm - Fermium - <257>	257	21.63081402	0.25088716
101 Md - Mendelevium - <258>	258	21.54697366	0.249914729
102 No - Nobelium - <259>	259	21.46378071	0.248949807
103 Lr - Lawrencium - <262>	262	21.21801223	0.246099237
104 Rf - Rutherfordium - <267>	267	20.82067118	0.241490637
105 Db - Dubnium - <268>	268	20.7429821	0.240589552
106 Sg - Seaborgium - <271>	271	20.513355	0.237926199
107 Bh - Bohrium - <272>	272	20.43793825	0.237051471
108 Hs - Hassium - <270>	270	20.58933039	0.238807407
109 Mt - Meitnerium - <276>	276	20.14173625	0.233615942
110 Ds - Darmstadtium - <281>	281	19.78334236	0.229459075
111 Rg - Roentgenium - <280>	285	19.50568142	0.226238596
112 Cn - Copernicium - <285>	285	19.50568142	0.226238596
113 Uut - Ununtrium - <284>	284	19.57436339	0.227035211
114 Fl - Flerovium - <289>	289	19.23570659	0.223107266
115 Uup - Ununpentium - <288>	288	19.30249724	0.223881944
116 Lv - Livermorium - <293>	293	18.97310309	0.220061433
117 Uus- <294>	294	18.90856872	0.219312925
118 Uuo - Ununoctium - <294>	294	18.90856872	0.219312925
Average		140.3485256	1.627846409

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