Muslim Education Quarterly, Vol. 23, No. 1 & 2, 2006
The Islamic Academy, Cambridge, U.K.

QUR'ĀNIC INFORMATION ON MALE-FEMALE CREATIONS AND THE HUMAN GENOME PROJECT (HGP) DATA: AN ANALYSIS FROM THE QUR'ĀN AND SCIENCE

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Introduction

Most organisms reproduce their own kind by the involvement of male and female parents—a process called sexual reproduction (Barton and Charlesworth, 1998 and the included citation). Parents endow their offspring with coded information in the form of *genes*. In plants and animals, reproductive cells such as sperm and ova transmit genes from one generation to the next. Transmission of parental genes takes place inside the cells by a process called *meiosis*. Therefore, in a sexually reproducing organism, offspring differ from parents and siblings appreciably by the closely controlled cellular meiotic mechanisms (Ramesh *et al*., 2005 and the included citations).

Many organisms also reproduce by *asexual* mechanism where a single individual passes along copies of all its genes to its offspring (Neiman 2004 and the included citation). Asexual reproduction similarly occurs at the cellular level and is called *mitosis*. Asexual reproduction produces offspring that are genetically identical to their parent (clone). Fission, budding, fragmentation, and the formation of rhizomes and stolons are some of the mechanisms that allow organisms to reproduce asexually. For example, the hydra produces buds to regenerate new ones. Starfish can regenerate an entire body from a fragment of the original body. Asexual reproduction allows an organism to rapidly produce many offspring without the time and resources needed for courtship, finding a mate and mating.

Despite the obvious efficiencies of many forms of asexual reproduction, sexual reproduction appears to abound in nature. This is because sexual reproduction generates endless genetic diversity by reshuffling the genes of an organism without compromising the organism's genetic integrity (Charlesworth 1991). As a result, each individual member of a particular species can easily be identified by their morphological, biochemical, or genetic differences. Finger printing or more advanced genetic fingerprinting analyses in humans are examples by which an individual can be identified from other members. Besides, sexual reproduction can put two beneficial mutations together or eliminate a deleterious one. It is believed that groups reproducing sexually can evolve more quickly than those who do not, because the combination of beneficial mutations will occur more quickly and deleterious

mutations will accumulate more slowly. Sexual reproduction is beneficial particularly in the unfavourable environmental conditions or when offspring are dispersed widely to end up in different environments (Waxman and Peck, 1999 and the included citations). This is why common grass grows asexually (locally) but produces seeds by sexual reproduction to travel away, so that in the new environments, there will be diversity for best adaptation.

Additional advantage of sexual mode of reproduction is that it allows organism to defend themselves against diseases (Kurtz, 2003 and the included citations). A particular genetic make up of an organism may be successful against its parasite in one generation but may fail to protect the organism's future generations. This is because the rate of evolution in parasites is very fast compared with their hosts. The only way in which an animal makes sure that its descendants will be able to deal with different parasites is to reproduce sexually. The arms races between parasites and their hosts are generally described by the lock and key analogy. Parasites invent new keys, hosts change the locks. If one lock becomes common in one generation, the key that fits it will spread like wildfire. As such, sexual reproduction persists because it enables host species to evolve new genetic defences against parasites that attempt to live off them. Whatever the benefits of sex may be, it is striking that practically all complex present-day organisms have evolved largely through generations of sexual, rather than asexual, reproduction.

A number of organisms, however, possess the option to employ one or the other mode of reproduction depending on the environmental condition (Green and Noakes, 1995 and the included citations). Rotifers (tiny aquatic animals, 0. 05 to 2 mm) will reproduce asexually when conditions are favourable by having females produce eggs by mitosis (Yoshinaga *et al.,* 2003). When conditions deteriorate, rotifers will reproduce sexually and encase their zygotes inside a resistant shell. Once conditions improve, these eggs hatch into diploid individuals. Rotifers thus use sexual reproduction as way to survive a deteriorating environment.

The advantages of sexual and asexual reproductive methods have been well documented in the scientific literature (Lobo and Onody, 2006 and the included citations). Nevertheless, how these reproductive methods evolved in the first place is not known. It is believed that the origin of sex may be linked with the first cell that evolved in the early earth. Almost four billion years have passed since the origin of the early earth and the formation of first cellular life-form, but it is not known how these species could evolve and maintain their integrity, and at the same time, demonstrate variations by involving different reproductive strategies. That an understanding of the origin of these reproductive strategies has remained as one of the most challenging areas of today's biology, is no wonder when one looks into the Qur'ānic verse which states that

> Glory be to Him who created pairs of all the things the earth produces and of themselves, and that of which they have no knowledge. (Qur'ān 36:36)

This appears to be a very powerful Qur'ānic verse because of the introductory word *subḥāna* (glory be to Him). There are only a few verses in the Qur'ān that start with this word (*subḥāna*) generally indicating events of enormous significance. In this

verse, Allah (SWT) mentions that the plants, animals, humans and all other creatures that humans possess no knowledge of, have been created in pairs. Several Qur'ānic verses, including 2:164, 4:1, 7:189, 13:3, 16:8, 16:72, 30:20-21, 39:6, 42:11, 43:12, 45:4, 51:49, 53:45-46, 75:39, 78:8, and 92:3 further support the message conveyed in verse 36:36.

First Life Form on the Earth: Looking Back into History

It is speculated that the first cellular life form evolved early in the history of the earth. How long ago that happened is not known. The precise age of the earth cannot be determined because the earth's oldest rocks have been recycled and destroyed by the process of plate tectonics. The earth's primordial rocks in their original state have not yet been found. As such, scientists calculate the age of the earth by assuming that the earth and the rest of the solid bodies in the solar system formed at the same time and are, therefore, of the same age (Lazcano *et al.,* 1983). The oldest rocks exceeding 3.5 billion years in age are, however, found on all of the earth's continents. Ataska Gneisses, the oldest rock found on the earth, occurs in northwestern Canada near Great Slave Lake (3.96 billion years), but well-studied rocks nearly as old are also found in the Minnesota River Valley and northern Michigan (3.5-3.7 billion years), in Swaziland (3.4-3.5 billion years), in Western Australia (3.4-3.6 billion years), and in western Greenland (3.7-3. 8 billion years). These ancient rocks are not from any sort of "primordial crust" but are lava flows and sediments deposited in shallow water that indicate that the earth's history began well before these rocks were deposited (Brent, 1991).

In Western Australia, single zircon crystals of ages as much as 4.3 billion years have been found, making these tiny crystals the oldest materials to be found on the earth so far. The source rocks for these zircon crystals have not yet been found. This shows that the earth is at least 4.3 billion years old. Additional support for such age of the earth comes from lunar rock analysis. The moon is believed to have been formed from the earth by a solar collision with a Mars size object in the past. Moreover, the moon is considered more primitive than the earth because it has not been disturbed by plate tectonics. The oldest dated moon rocks have ages between 4.4 and 4.5 billion years and provide a minimum age of the earth in this range. Additional studies from meteorite analysis show that the solar system formed between 4.53 and 4.58 billion years ago. The best age of 4.54 billion years found for the earth is generally consistent with most analytical studies (Zhang, 2002 and the included citations).

It is believed that the first cellular organism might have appeared early in the history of the earth, about 3.5-4.0 billion years ago. It is speculated that the earth's crust had been solidified about 4. 1 billion years ago. This allowed the first prokaryotic organisms (bacteria) to advance enough and build stromatolites. Fossils similar to round and filamentous prokaryote have been recovered from stromatolites 3.5 billion years old in Australia (Brasier *et al.,* 2005). As such, in the remaining sections of this analysis, 3.5 billion years will be quoted as the time when life first appeared on the earth. Interestingly, these prokaryotes have remained in existence until today. What had happened to these bacteria during their 3.5 billion years of existence is not known. Because of absence of nucleus in their cells, prokaryotes were once considered to be able to reproduce only clone-like offspring.

However, studies have already shown that even bacteria undergo sexual conjugation to produce different variants of offspring (Riley, 2005 and the included

citations). In the process of bacterial conjugation, one bacterium ("male") donates DNA and its "mate" ("female") receives the genes. A sex pilus from the male initially joins the two cells and creates a cytoplasmic bridge between the cells. The "maleness" allows the forming of a sex pilus and of donating DNA that result from an F factor (a section of the bacterial chromosome or as a plasmid). Cells with either the F factor or the F plasmid are called F^+ and they pass this condition to their offspring. Cells lacking either form of the F factor are called F^-, and they function as DNA recipients. When an F^+ and an F^- cells meet, the F^+ cell passes a copy of the F plasmid to the F^- cell, converting it to F^+. The plasmid form of the F factor can also become integrated into the bacterial chromosome. Such a cell will be called the Hfr (high frequency of recombination) cell. Hfr cell functions as a male during conjugation. The Hfr cell initiates DNA replication at a point on the F factor DNA and begins to transfer the DNA copy from that point to its F^- partner. It is no wonder that Allah (SWT) mentions this in the Qur'ānic verse 36:36, which is further supported by verse 51:49 which states that

> And of everything We have created pairs, that you may remember (the Grace of Allah). (Qur'ān, 51:49)

The impact of such "sexual" conjugation on the ancient bacterial populations appears less likely to be understood clearly. The precise time period for such a conjugation process to evolve in the past has not been known. Nor is it known clearly if the conjugation process had any impact on the evolution of other species. However, conjugation allows bacteria to diversify, and today, after three and a half billions years of existence, prokaryotes still continue to diversify and dominate the biosphere. Their collective biomass outweighs all eukaryotes combined at least by ten-fold. More prokaryotes inhabit a handful of fertile soil or the mouth or skin of a human than the total number of people who have ever lived on the earth. By some estimates, only about 5,000 species of prokaryotes are currently known, and the actual prokaryotic diversity may range from about 400,000 to 1 billion species (Pedrós-Alió, 2006 and the included citations). According to such speculation, more than 99.9% of the prokaryotic organisms still remain unknown. That mankind possesses so limited knowledge of the great majority of the prokaryotic organisms and their male-female characteristics appear to be unimaginable in the light of current, more advanced state of science. Thus, it becomes easier to understand the word at the beginning of verse 36:36, "glory be to Him", since Allah (SWT) introduces another extremely important fact to mankind by saying "and of that which they know not". That the mankind does not know what Allah (SWT) has created in pairs, is further supported in the Qur'ānic verse 16:8 which states that

> And (He has created) horses, mules and donkeys, for you to ride and as an adornment. And He creates (other) things of which you have no knowledge. (Qur'ān, 16:8)

Advanced Cellular Life Forms

It is speculated that after about one and a half billion years of prokaryotic existence on the earth, a new type of organisms started to emerge in nature. These are known as

eukaryotic organisms because they acquired nucleus into their cells. The eukaryotes continued to exist and evolve for the subsequent two billion years, that is, until now (Bui *et al.,* 1996 and the included citations). These cellular organisms are believed to have evolved from a symbiotic association of early prokaryotic organisms. The eukaryotes consisted of mostly microscopic organisms known by the informal name "protists". Modern day protists include about 60,000 different species with widely different characteristics. These organisms would reproduce by sexual (meiosis) or asexual mode (mitosis); meiosis is believed to have evolved from mitosis in these eukaryotic organisms. However, the mechanism by which sexual processes evolved and advanced from prokaryotic to eukaryotic and then, among the eukaryotic species has not so far been delineated with convincing evidence. It is apparent that for nearly the entire period of three and a half billion years, only the unicellular prokaryotes and eukaryotes dominated the face of the earth. Mankind did not exist for such a long period of time though the earth had activities filled with different cellular life forms. This appears to have been supported in the Qur'ānic verse 76:1 where Allah (SWT) says,

> Has there not been over man a period of time, when he was not a thing worth mentioning? (Qur'ān, 76:1)

Higher Organisms

Multicellular, more advanced organisms started to evolve during the last half a billion years from their eukaryotic ancestors. Today, some estimates speculate that there probably exist about 10 to 100 million different biological species in nature (Odegaard, 2000). Of these, according to All Species Foundation data (http://www.all-species.org), only 1.7 million species have so far been described in the scientific literature. Moreover, it is believed that the currently existing species represent only 1% of all the organisms that once inhabited the earth. To understand the origin of sex in all these species appears to be impossible, especially when 99% of the biodiversity has already been extinct and more than 80% of the remaining species have not been studied at all! Thus, it is quite apparent that the verse 36:36 not only applies to microscopic prokaryotic species; rather, it probably applies to all types of creation. The Qur'ānic verses 2:164, 16:8 (cited above), and 45:4 lend further support to verse 36:36:

> Verily, in the creation of the heavens and the earth, and in the alternation of night and day, and the ships which sail through the sea with that which is of use to mankind, and the water which Allah sends down from the sky and makes the earth alive therewith after its death, and the moving creatures of all kinds that He has spread therein, and in the veering of winds and clouds which are held between the sky and the earth, are indeed signs for people of understanding. (Qur'ān, 2:164)

> And in your creation, and what He scattered (through the earth) of moving (living) creatures are signs for people who have faith with certainty. (Qur'ān, 45:4)

Of the extant species that have so far been studied include 270,000 plant species (Coleman and Whitman, 2005), 42,000 vertebrate animals and 750,000 insects.

Interestingly, these species are thought to have evolved from ancestral species that originated during a short period of time (between 543 to 525 million years ago). This is known as the "Cambrian Era". It is also known as Biology's Big Bang or the Cambrian Explosion because of the great diversity of life that evolved suddenly during this time (McCall, 2006 and the included citations). The first appearance of limbs and segmented bodies along with the development of shells, jaws, claws, and teeth seem to have taken place during this time. The first organisms to be predators also evolved along with millions of different life forms, all of which would spend most of their time on the muddy sea floor. No creatures had initially travelled on land and yet, within about next 10 million years, this same stock would give rise to millions of different forms, shapes, sizes and abilities such that these new organisms would fly, swim and crawl on land. How so many different types of species could evolve abruptly in such a short period of time is not known. But it is speculated that the ancestor of the true animals could have been a colonial flagellated protist that lived about 700 million years ago in the Precambrian era. A further ancestor of this protist (a probable choanoflagellates) is thought to have evolved about a billion years ago. Plant, on the other hand, is believed to have initially originated from aquatic ancestors about 475 million years ago which might have originated from early eukaryotes such as, charophytes.

Origin of Sex

Scientists believe that the sex first evolved among the unicellular organisms (Michod, 1998). Current understanding of meiosis and bacterial conjugation (Davison, 1999) mechanisms appears to indicate that both prokaryotic and eukaryotic organisms probably employed complex methods for their gradual progression from simpler to more complex form. This suggests that the origin of sex may be linked with those initial cellular life forms that probably flourished some three and a half billion years ago. Such understanding appears to be the theme of verse 36:36, which is in harmony with the Qur'ānic statement 51:49 (mentioned above) and 43:12 where Allah (SWT) says,

> And Who has created all the pairs and has appointed for you ships and cattle on which you ride? (43:12)

Scientists generally consider meiosis as the only mechanism of sexual reproduction (Marais, 2003 and the included citations). They suggest that meiosis-dependent sex first evolved in the unicellular eukaryotes. These organisms acquired nucleus and, therefore, could undertake the sexual mode of reproduction. As such, according to their view, sex probably evolved about two billion years ago with the origin of eukaryotic organisms. Some scientists hold the opinion that *Saccharomyces pombe* (a type of yeast) could be a probable candidate because *Saccharomyces cerevisiae* (a different species of yeast from the same genus; see review by Zeyl, 2004 and the included citations) shows an elaborate and well-known meiotic process though the *S. pombe* employs much simpler meiotic mechanism. Yet others suggest that protists having optional or alternative sexual and asexual cycles must be the best targets for research on the evolution of sex (Birky, 2005 and the included citations). As such,

neither the specific type of eukaryotic organisms nor the mechanism by which meiosis first evolved could be delineated until now. A specific time-frame when meiosis evolved in the past (and therefore sex) could not be determined either. As stated already, lack of human understanding of origin of sex is not surprising in the light of what Allah (SWT) has stated in verse 36:36; one may also look into the Qur'ānic verse 53:45, where Allah (SWT) says,

> And that He (Allah) creates the pairs, male and female. (Qur'ān 53:45)

Indirect Approach to Understand the Origin of Sex

Lack of direct data led scientists to seek for alternative ways to understand the origin of sex in eukaryotic organisms. It is known that the sexual reproduction (meiosis) is advantageous over the asexual method not only because the characteristic features of every species are conserved; but, also because sexual reproduction allows newer variations to emerge in the next generation. This allows newer life forms to evolve faster than the asexual methods. If such sexual reproduction continues, then over a certain time, the process of meiosis should produce a tree-like pattern of evolution for all new species. If the process of meiosis could evolve among the early eukaryotes (two billion years ago) then, a tree-like pattern of evolution could be observed beginning at that particular period of time. In contrast, a tree like pattern of eukaryotic evolution is speculated to have taken place only about 550 million years ago during the Cambrian Era. As such, this indirect observation suggests that the cellular sexual reproduction may have evolved abruptly sometime about 550 million years ago.

Nevertheless, it is believed that the meiosis in eukaryotes probably set the stage for evolution about two billions years ago, which ultimately produced the tree-like branching pattern much later. Understandably, the speculation varies a lot and neither the time when (a wide range, from 2 billions to 550 millions years ago) nor the species in which meiosis first evolved could be determined. It is important to note that without the meiotic reproductive process, the first colonial unicellular life forms could not evolve. These colonial cells are believed to have played a critical role because they underwent further differentiation to produce multicellular life forms. And it is the multicellular life forms in which the visibly differentiated sex could evolve (Liu *et al*., 2004).

Problem of Sex in Multicellular Life Forms

Asexual and sexual reproductions are cellular processes (that is, mitosis and meiosis, respectively). This means, it is easier for a single cell to reproduce by either of the two ways. This scenario gets far more complicated for a multicellular organism. For example, an average 70 kilogram human body possesses more than 100 trillion cells. These cells differ structurally and functionally from one another depending on the tissues and organs they form. For these multicellular life forms, new types of cells were needed that would be dedicated for the organism's reproductive purposes. It is believed that, in some of the early multicellular organisms, some cells started to differentiate into germ cells (also called gamete). Precisely how and in which organisms that happened first could not so far be ascertained.

The germ cells are the sperm (in male species) and egg cells (in female species), together with their precursor cells. All the rest of the cells would be called the somatic cells of the body. These somatic cells are responsible for all bodily functions other than the sex. Species would conserve their whole body characteristics and integrity by maintaining fixed pairs (two sets) of chromosomes in the somatic cell. For humans, each somatic cell contains 23 pairs of chromosome that include 22 pairs of normal chromosomes and one pair of sex chromosomes (XX for female or XY for male). Somatic cell is, thus, represented as 46XX or 46XY; 46 to indicate the total number of chromosomes while XX or XY to indicate the female or male sex respectively. In contrast, each egg or sperm cell contains only 23 *individual* chromosomes consisting of 22 normal chromosomes and one X chromosome (for egg) or 22 regular chromosomes plus either one X or one Y chromosome (for sperm). As such, the sex determining system is also called the X-Y system though some organisms follow different mechanisms.

Mechanism of Sex Determination in Multicellular Organisms

One of the greatest problems in the germ cell-mediated sex determination in multicellular organisms is that these cells do not follow a unified mechanism. In other words, male and female germ cells may employ one of the X-Y, X-O, or Z-W systems (or no sex chromosome systems; described below). This appears to be a major obstacle why a step-wise evolutionary pattern for origin of sex could not so far be identified in nature.

X-Y system

X-Y system is most common among the mammals, including the humans. In human, out of 23 pairs of chromosomes, 22 pairs are known as autosomes; that is, they are common both in male and in female. The other pair, as mentioned already, would be either XX (for female) or XY (for male). The karyotype (chromosome type) of a human male is, therefore, 46XY, and that of a female is 46XX. This would mean that an egg (female germ cell) can only be 23X while a sperm could either be 23X or 23Y. Combination of sperm and egg, thus, restores 46XX (female) or 46XY (male) to develop into a new-generation individual. In mammals, as a whole, the presence or absence of the Y chromosome usually determines sex. In other words, it is the male sperm that determines sex for the next generation offspring.

People at all ages in the past have asked this fundamental question like what makes a child male or female. It is only in the twentieth century that the biologist could successfully find the answer. Yet, one would be surprised to know that an extremely small percentage of today's populations are really familiar with such information. Amazingly, Prophet Muhammad (peace be upon him) had passed this information to his companions early in the seventh century as has been recorded in several *ḥadīths*. On several occasions, Prophet Muhammad (peace be upon him) was asked about the creation of males and females. And, he (peace be upon him) explained this information to his companions in a manner appropriate and suitable to their personal levels of understanding that existed at that time (14 centuries ago). Two important ḥadīths that have been narrated by *Muslim* in this respect are included below.

1. Book 003, Number 0613:

It is reported on the authority of 'Ā'isha that a woman came to the Messenger of Allah (peace be upon him) and inquired: Should a woman wash herself when she sees a sexual dream and sees (the marks) of liquid? He (the Holy Prophet) said: Yes. 'Ā'isha said to her: May your hand be covered with dust and injured. She narrated: The Messenger of Allah (peace be upon him) said: Leave her alone. In what way does the child resemble her but for the fact that when the female substance contributed by woman prevail upon those of man, the child resembles the maternal family, and when the male reproductive substance prevail upon those of woman the child resembles the paternal family. The meaning of this ḥadīth has been included at the end of the following ḥadīth.

2. Book 003, Number 0614:

Thauban, the freed slave of the Messenger of Allah (peace be upon him), said: While I was standing beside the Messenger of Allah (may peace be upon him) one of the rabbis of the Jews came and said: Peace be upon you, O Muhammad. I pushed him back with such a push that he was going to fall. Upon this he said: Why do you push me? I said: Why don't you say: O Messenger of Allah? The Jew said: We call him by the name by which he was named by his family. The Messenger of Allah (peace be upon him) said: My name is Muhammad with which I was named by my family. The Jew said: I have come to ask you (something). The Messenger of Allah (peace be upon him) said: Should that thing be of any benefit to you, if I tell you that? He (the Jew) said: I will lend my ears to it. The Messenger of Allah (peace be upon him) drew a line with the help of the stick that he had with him and then said: Ask (whatever you like). Thereupon the Jew said: Where would the human beings be on the Day when the earth would change into another earth and the heavens too (would change into other heavens)? The Messenger of Allah (peace be upon him) said: They would be in darkness beside the Bridge. He (the Jew) again said: Who amongst people would be the first to cross (this bridge)? He said: They would be the poor amongst the refugees. The Jew said: What would constitute their breakfast when they would enter Paradise? He (the Holy Prophet) replied: A caul of the fish-liver. He (the Jew) said: What would be their food alter this? He (the Holy Prophet) said: A bullock which was fed in the different quarters of Paradise would be slaughtered for them. He (the Jew) said: What would be their drink? He (the Holy Prophet) said: They would be given drink from the fountain which is named "Salsabīl". He (the Jew) said: I have come to ask you about a thing which no one amongst the people on the earth knows except an apostle or one or two men besides him. He (the Holy Prophet) said: Would it benefit you if I tell you that? He (the Jew) said: I would lend ears to that. He then said: I have come to ask you about the child. He (the Holy Prophet) said: The reproductive substance of man is white and that of woman (i.e. ovum central portion) yellow, and when they have sexual intercourse and the male's substance prevails upon the female's substance, it is the male child that is created by Allah's Decree, and when the substance of the female prevails upon the substance contributed by the male, a female child is formed by the Decree of Allah. The Jew said: What you have said is true; verily you are an Apostle. He then returned and went away. The Messenger of Allah (peace be upon him) said: he asked me about such and such things of which I

have had no knowledge till Allah gave me that!

According to the Thauban *ḥadīth*—a male (X-Y) child results when the "male's substance (Y) prevails upon the female's substance (X), and a female (X-X) child results "when the substance of the female (X) prevails upon the substance contributed by the male". This meaning also applies to the ḥadīth narrated by 'Ā'isha. It should be noted that, according to modern scientific terminology, the male and female substances mean the Y or X chromosomes, respectively. Scholars in Islam need to take caution interpreting this ḥadīth, which has originally been described for human situations. This ḥadīth does not talk about other mammalian species though the same mechanism might determine sex in other mammalian species as well. This caution should be practised because exceptional mammalian species could exist that may not follow this mechanism. More importantly, there exists hundreds of different animal species where male sperm does not determine the sex at all (described later, under the Z-W chromosome system)! It is interesting that the prophet (peace be upon him) got this modern-day understanding about 14 centuries ago as emphasized by the statement, "he asked me about such and such things of which I have had no knowledge till Allah gave me that"!

The X-Y mediated sex determination system has been found to be extremely variable (Graves, 2002). And because of these variations (described below), the X-Y method of sex determination has so far been considered as far from universal. For example, the mammalian Y is smaller than the X though in the plant, *Silene latifolia* Y chromosome is larger than its X. Of the 270,000 extant plant species (Coleman and Whitman, 2005), most develop flowers with both male and female sex organs in the same flower (monoecious plants). However, there exist several thousands of dioecious plant species where male or female flowers form on different individuals. Interestingly, the presence of well-established sex chromosomes in these dioecious plants is rare (Vyskot and Hobza, 2005). Such intricate complexities seem to have rightly been acknowledged in the Qur'ānic verse 36:36, which is further supported in verse 13:3 where Allah (SWT) says,

> And it is He Who spread out the earth, and placed therein firm mountains and rivers and of every kind of fruit He made two in pairs. He brings the night as a cover over the day. Verily, in these things, there are *āyāt* (proofs, evidence, lessons, signs, etc.) for people who reflect. (Qur'ān, 13:3)

The behaviour of X-Y sex chromosomes also varies extremely in the animal worlds. It has already been mentioned that, for humans, it is the male sperm (presence of Y chromosome) that determines the sex for the next generation offspring. In fruit flies, on the other hand, the ratio of X chromosomes to autosomes is crucial to develop male-female characteristics (Ray and Fox, 2005 and the included citations). In crocodiles and other reptiles, chromosomes have a marginal role—the temperature at which eggs are incubated is the key (Sarre *et al.,* 2004). Slipper limpets, which form stacks attached to seashore rocks, change sex according to their position in the stack (1978). Even more bizarre is the marine worm, *Bonellia viridis*. Its larvae settle on the ocean floor and turn into 10-cm long females. Other larvae are attracted to the worm's proboscis, and when they land on it they are ingested and turn into tiny sperm-

producing symbiotic males in the female gut (Jaccarini *et al.,* 1983). Among the tetrapod vertebrates that possess microscopically similar X and Y chromosomes, there exists a wide diversity of sex determination mechanisms. Even wider ranges of sex determining systems are found in teleost fishes that include self-fertilizing hermaphrodites, sequential hermaphrodites, and environmental sex determination (Idler *et al.,* 1976). Understanding how the X-Y system could diversify itself into so many ways and also to pinpoint their origin appears to be a great puzzle for the modern day biologists. Such hurdles readily reinforce the truth stated in Qur'ānic verse 36:36; interested readers might also find verses 16:8, 43:12, 51:49, and 92:3 as indicative of human limitations on the paired creations of species.

Origin of X-Y Chromosome

Researchers have been investigating for decades on several key questions including when, how, and in which species the X-Y system could have been originated first (Graves *et al.,* 2006; Graves, 2006; Kohn *et al.,* 2004; Graves, 2002). Some studies speculate that the X and Y chromosomes dependent sex arose about 80-130 million years ago among some mammalian ancestors (Waters *et al.,* 2001). It is believed that the X and the Y chromosomes were originally a pair of identical sister chromosomes like any other pair of autosomes. It is also speculated that about 300 million years ago such pairs of chromosomes probably existed in a reptilian species where one of them (obviously the Y chromosome) had to undergo an accidental mutation (Lahn and Page, 1999). As a result, a sex-differentiating gene appeared in Y chromosome that might have allowed Y chromosome to direct the development of sperm-producing testes. It is known that sex did exist among the reptiles 300 million years ago but, without the involvement of X or Y chromosomes. Environmental cues such as temperature or other factors would determine whether an animal develops as male or female. Such system is still in place in turtles and other reptiles where sex can be determined only by chance or uncertain environmental events (Sarre *et al.,* 2004 and the included citations). Alternative hypotheses also exist; one such hypothesis is advocating for the epigenetic mechanism of X-Y chromosome evolution (Jablonka, 2004 and the included citations; Valley and Willard, 2006) rather than accidental mutation. It seems that the epigenetic view is fast getting acceptance; therefore, it will probably be some time before one can judge the different views of X-Y evolution. Irrespective of the mechanism by which they originate, the X-Y chromosomes are real and they do determine sex. They mediate a precisely controlled reproductive mechanism among mammalian species and eliminate the uncertain chance factors during reproduction. They also maintain an approximately one-to-one male-female ratio during reproduction.

The benefit of X-Y mechanism of reproduction has been well documented in science, but there are no convincing scientific proofs about the origin of this mechanism. It does not seem likely to find any direct evidence of X-Y chromosome evolution either, since it is not possible to go back into the different time periods in the past. The key issue that how the X-Y pair of chromosomes could gradually evolve into humans from a pair of ordinary autosomes would perhaps continue to challenge the human minds in future. It is true that the Y chromosome has different morphology and gene content than X; the scientific argument that the Y chromosome gains these by an accidental mutation constitutes a "faith", or more appropriately, a "scientific

faith". Besides, what science sees as accident, Qur'ān declares it to be the will of Allah (SWT). The Qur'ānic verse 36:36 firmly establishes this truth and is further supported in the following verses.

> The Creator of the heavens and the earth. He has made for you mates from yourselves and for the cattle (also) mates. By this means He creates you (in the wombs). There is nothing like unto Him, and He is the All-Hearer, the All-Seer. (Qur'ān, 42:11)
>
> And He made him in two sexes, male and female. (Qur'ān, 75:39)
>
> And We have created you in pairs. (Qur'ān, 78:8)
>
> And by Him Who created male and female. (Qur'ān, 92:3)

Another major obstacle that challenged the contemporary biologists was to find an acceptable mechanism by which the human Y chromosome could shrink to 1/6th of the size of its counterpart, that is, the X chromosome. It is well known that the recombination is a key event of meiosis in which two identical chromosomes pair up and exchange their sequences to produce new varieties of individuals. As such, it is believed that the suppression of X-Y recombination should greatly affect the Y-chromosome integrity. The X chromosome can recombine along its whole length with a sister X whenever it passes through a female. Since the Y chromosome did not recombine along most of its length it could disintegrate easily without compromising cellular functions. This is because, without recombination, DNA rearrangements accumulate, genes decay, and useless bits of DNA amplify. When DNA becomes useless, repetitive and devoid of genes, cells can toss it out without suffering any damage (Lahn and Page, 1999).

Scientifically, one can assume that with time, the mutated Y chromosome started to focus only on male-making and dropped most of its previous duties. By literally shedding all but a core of about 78 genes, the Y gradually shrank to about one-sixth the size of the X. By such assumption, the functions of those lost genes had to be carried out by its unmutated partner, the X chromosome. Because of the loss of Y genes it once shared with the X, the X-Y chromosomes cannot recombine gene-by-gene during the production of sperm or egg. Rather, they now recombine only over a very small region at the tip (About five percent of the Y chromosome). This region is called the pseudoautosomal region. The pseudoautosomal region is more gene-rich than the rest of the Y chromosome. Several of the genes on the pseudoautosomal region of the Y also have counterparts on X. Such similarity has been considered as an indication that the X and Y may have evolved from a common ancestor some 300 millions years ago (Lahn and Page, 1999).

Many studies, however, speculate that the absence of recombination would make Y chromosomes unable to repair itself thereby leading to its extinction. The mammalian Y chromosome had degenerated to such an extent that these studies have assumed that it did nothing except determining the maleness. These studies also speculate that the continued degradation of the Y chromosome might result in its complete degeneration (Graves, 2006 and the included citations); in reality, this

should otherwise mean an extinction of the human males. Despite these speculations, many biologists hold the belief that the future extinction of human male species is unlikely. Such an idea gains support from observations that have indicated that the degeneration of the Y had been offset at various times in the past. They suggest that the offset of Y degeneration had been mediated by additions of autosomal genes to Y chromosome (as well as to X). This had led to a pattern of loss and gain of genetic material in Y chromosomes over a period of about 170 million years (Charlesworth and Charlesworth, 2005).

The above discussion suggests that the mechanism of X-Y origin has not been established from direct observations that could produce a solid scientific conclusion. Rather, an assumed accidental mutation, long time ago, becomes the basis of many scientific conclusions. No conclusive data are available that could describe the step-by-step evolution of X-Y chromosomes beginning from the reptilian ancestors till modern humans. The assumption that more than 85% of Y chromosome's nucleotide sequences have been lost during a period of 300 million years comes from the existing evolutionary theory that suggests that the evolution of humans from reptiles required about 300 million years. In other words, until now, the researches on X-Y origin have mostly been aimed at obtaining data that would fit the existing reality only. Many of the currently proposed scientific theories thus rationalize already existing natural phenomena by using recently completed HGP (Human Genome Project) data. However, the way by which the HGP data are interpreted to support the origin of males and females (by accidental mutation, etc.) seems to constitute a "scientific faith", as mentioned already.

If one realizes how much one has to depend on faith and chance factors to accept the proposed mechanism of X-Y origin, and that is also in the name of science which is ever-changing, then one would readily understand why the verse 36:36 starts with a powerful statement, "glory be to Him"; without contradicting any solid scientific data, this statement nullifies all those chance factors and rightly reiterates that no power, but Allah, has the ability to create an extraordinarily complicated male-female relationships in a manner that is highly specific for each of those known and unknown life forms. Such amazing male-female relationships has further been supported in Qur'ānic verses 42:11 (listed above) and 30:21; the latter verse states that

> And among His signs is this that He created for you wives from among yourselves, that you may find repose in them, and He has put between you affection and mercy. (Qur'ān, 30:21)

The Qur'ānic verse 36:36 has directly indicated that Allah (SWT) has created all species in paired forms. Interestingly, the verses 30:21 and 42:11 mention that, for humans, even each of the pairs (that is husband and wife) has also been created independently. This probably suggests that one need not consider the creation of males and females only from a general point of view; for example, by the involvement of X and Y chromosomes only. Rather, the chromosomes X-Y and whatsoever is needed to create the males, females, and the independent pairs, have been created by Allah (SWT) according to His plan. It is worthwhile to note that one can explain the differences between the human female and male in terms of the presence of X or Y, but how can one determine the love and kindness that develop between husband and wife?

The Degenerating Y, the Integrity of Sex, and X-inactivation

Biologists appear to have been confronted with many challenges just to understand how the X-Y system can function with enormous precision rather than creating chaos. For example, many biologists do acknowledge that the loss of genes from Y chromosomes should have presented life-threatening problems for effective and balanced practices of the male and female species. This is because, with the greatly reduced Y (about 78 genes to produce only 23 proteins) and a normal X chromosome (1098 genes), a human male practically retained only one copy of those critical genes whereas, a female continued to have two copies of these genes, intact on her two X chromosomes. Females thus possess double the dose of genes compared with males. Despite such differences, biologists were initially surprised to find that males and females still continue to perform normal physiological functions. Today, biologists know that at least two mechanisms are operating in nature to counterbalance such differences in gene expressions between males and females. For some species, gene activities on the one X present in males have been increased to produce twice as much in males as in females. For other species, the expressions of X-linked genes have been decreased in females possessing two X chromosomes by a special mechanism called X-inactivation.

The first mechanism is seen in some insects, including *Drosophila*, while mammals use the X-inactivation mechanism to balance their gene activities (Ray and Fox, 2005; Willard, 2005; Valley and Willard, 2006). In X-inactivation, female embryos randomly inactivate one X chromosome in each of her cells. X-inactivation requires a locus on the X, called the X-inactivation center. At this locus, inactivation occurs in response to a developmental cue, which is present only at specific stages of embryonic development. Inactivation occurs because of a specific type of RNA, which binds to one X chromosome, preventing transcription of the genes on this particular copy. In addition, enzymes add methyl groups to the DNA of the inactive X, resulting in repression of transcription. It may sound amazing, but for proper functioning of the X-Y system, the Y chromosome had to lose its similarity with the X, and the X chromosome inactivation had to occur immediately; almost side-by-side. What biological process could facilitate such simultaneous fine-tuning of X-Y evolution remains a great mystery for today's biologists. It is no wonder that Allah (SWT) had to swear by His glory in verse 36:36 to convince mankind that creation of male and female among all the known and unknown species was possible only by the will of Allah.

Strange Features of the Inactivated X chromosome in Female

The recently completed HGP data also suggest that some 15 percent of the inactivated X chromosomes in women routinely remain active, at least partly (Willard 2005; Graves, 2006). This figure can reach up to 25 percent of the X-inactivated chromosomes in some women. These data suggest that about 200 genes may still remain functional in the inactivated chromosome. The implication of such a large number of functional genes in the inactive X chromosome in females is not clear at this time. Scientists speculate that this could be attributed to the biological differences between the males and females. It could also be attributed to the differences in responses to drugs and susceptibility to some diseases in females. Considerable

variations in the gene activation pattern from woman to woman also provide evidence that women as a group may be more variable than men.

More interestingly, studies have suggested that the genes that escape X inactivation in females also have conserved Y cousins (or homologs) (Willard 2005; Graves, 2006 and the included citations). The homologs on the Y appear functionally interchangeable with their cousins on the X. Several Y genes that have decayed, or whose function has become limited, still have X homologs that escape X inactivation. But no cases are known in which a gene is subject to X inactivation and yet has a Y homolog that remains conserved in structure and widely expressed. Biologists conclude that the Y degeneration preceded the expansion of X inactivation. In other words, the decay of genes on the Y drove the acquisition of X inactivation. The detailed knowledge regarding how, when, and in what species such mechanism could first originate is currently unknown.

Benefit of Y chromosome

The HGP data show one benefit of Y chromosome in that the genes on the part of the Y chromosome that do not recombine with X will be passed from father to son, down a paternal lineage, and will never be found in females. For example, the genes required for male fertility are found in the non-recombining regions of the Y, and are not present on X (Ali and Hasnain, 2003). The lack of recombination means that the entire non-recombining portion of the Y is passed intact from father to son. A male shares the same Y chromosome with his father, paternal grandfather, paternal great-grandfather, and so on. Because these regions do not recombine they change very slowly, so they may be useful in identifying stable paternal lineages over thousands of years.

X-O system

Some animals employ a different variant of X-Y system for their sex determination. For example, grasshoppers, roaches, and other insects use X-O system to determine the sex of an individual. Adult males lack a Y sex chromosome and have only an X chromosome. They produce sperm cells that contain either an X chromosome or no sex chromosome, which is designated as O. The females are XX and produce egg cells that contain an X chromosome. If an X sperm cell fertilizes an egg, the resulting zygote will be XX or female. If a sperm cell containing no sex chromosome fertilizes an egg, the resulting zygote will be XO or male. It has already been mentioned that the Thauban ḥadīth has originally been mentioned only for human situation. However, it would not be wrong to infer that the Thauban ḥadīth could also be valid not only for most mammals, but also for the X-O system animals since it is the male substance that determine sex in these animals.

Z-W system

Many organisms employ other mechanisms rather than the X-Y system. Birds, insects, and some species of fish determine their gender using the Z-W system (Smith and Sinclair, 2004). In these animals, it is the female gamete that determines the sex of an individual. Female gametes can either contain a Z chromosome or a W

chromosome. Male gametes contain only the Z chromosome. Females of these species are ZW and males are ZZ.

No Sex Chromosome System

Some animals including most kinds of wasps, bees and ants do not possess any sex chromosomes. In these species, fertilization determines gender. If an egg becomes fertilized it would develop into a female. A non-fertilized egg may develop into a male by a process called parthenogenesis (Neiman, 2004; Sarre *et al.,* 2004). The female contains two sets of chromosomes, while the male contains only one set. Many dioecious plants, including papaya and kiwi fruit, do not possess any sex chromosome either; rather, an autosomal gene determines the sex in these species (Liu *et al.,* 2004 and the included citations). It is obvious that the Thauban ḥadīth would not be valid either for the Z-W Systems or for the no-sex-chromosome-system species.

Other Scientific Theories on the Origin of Males and Females

In the literature of biological sciences, theories and hypotheses are plentiful that attempt to explain questions related to origin of males and females. Some theories draw conclusions based on different factors rather than the HGP data. Of particular importance is the theory called the two-fold cost of sex (Agrawal, 2001). According to this theory, the evolution and continuity of sexual reproduction do not fit in nature. This is because organisms, that multiply asexually, have a two-fold fitness advantage over their sexual counterparts since every individual has the potential to reproduce. As a result, these organisms should rapidly outnumber a sexually reproducing population. However, "the theory of ecological cost of sex" advocates that the sexual reproduction prevails in nature because the earth possesses certain set-conditions that limit the success of asexual reproduction (Doncaster *et al.,* 2000).

It is no wonder that currently there exist many hypotheses that give different explanations to support the origin of males and females in nature (reviewed in Doncaster *et al.,* 2000; West and Peters, 2002; Agrawal, 2001; Ridley, 2003). A closer examination of these hypotheses shows that there are tendencies among researchers to justify the ecological adaptive fight against diseases, or other factors as key regulators in the origin of sex. All these hypotheses have limitations and the biologists face tremendous hurdles to provide satisfactory biochemical answers to many of the currently unresolved questions. For higher organisms including the humans, simpler questions like how the first fully functional female and the first fully functional male originated simultaneously remain a great puzzle. Explaining the origin of sex by a unified theme has, so far, been unsuccessful. This is because, according to scientific postulates, millions of different species had lived on the earth in the past where sex appears to have evolved differently. In the light of such scientific understanding, one can easily conclude that the males and females probably evolved in a species-specific manner, contradictory to any gradual, step-by-step evolution.

Qur'ānic Teaching on Male-Female Creation

In verse 36:36, Allah (SWT) swears by His glory that the males and females, among all the known and unknown species, have been created solely by Allah (SWT).

Further support for verse 36:36 can be drawn from many other Qur'ānic verses including, 2:164, 4:1, 7:189, 13:3, 16:8, 16:72, 30:20-21, 39:6, 42:11, 43:12, 45:4, 51:49, 53:45-46, 75:39, 78:8, and 92:3. Surprisingly, the explanation (*tafsīr*) of verse 36:36 seems to be limited in the contemporary Islamic literature; interpretation of verse 36:36 from the standpoint of current scientific understanding is also lacking. The limited explanation (*tafsīr*) of verse 36:36 seems unusual when compared with the lengthy narrations available on verse 17:1 in the ḥadīth literature dealing with the Night Journey (*mi'rāj*) of the Prophet; both verses begin similarly with the statement "glory be to Him". Even the Thauban ḥadīth appears to have been ignored rather than being explained in a more scientific way. An extremely slow pace of scientific understanding on the origin of males and females during the last fourteen hundred years may be one reason why explanations of verse 36:36 and of the Thauban ḥadīth have not been attempted. This is surprising if one realizes that the basic explanation of male-female creations (Thauban *ḥadīth*) has already existed in different *aḥadīth* (pl. of *ḥadīth*) during all these years.

Integrating Islam and Science: Verse 36:36 as an Example

A limited interpretation of verse 36:36 and the related *aḥadīth* makes it difficult to integrate the current scientific understanding with the revealed knowledge. To explore whether the Islamic knowledge of male-female creations is in harmony with today's scientific understanding, one needs to look at the evidence from the latest scientific research that deals with the problems of the origin of sex. The current analysis documents those latest scientific findings (including the HGP data) to show that the HGP data are being exploited by the biologists in a different manner; biologists are combining HGP data with their proposed accidental mutations or chance factors to prove the natural evolution of X-Y chromosome rather than accepting creation by Allah (SWT). In contrast, this analysis shows that the HGP data, without considering the chance-related interpretation, should be in harmony with the overall theme of verse 36:36. This analysis thus suggests that the fundamental scientific research helps understand the greater meaning of revealed knowledge such as that mentioned in verse 36:36. In this analysis, the verse 36:36 has been interpreted using many relevant Qur'ānic verses and *aḥadīth*; this is because, science alone cannot provide the meaning of Qur'ānic verses. The interpretation of natural phenomena available in science is always changing while the Qur'ān describes the everlasting truth of nature. These additional Qur'ānic verses should, therefore, provide the fundamental meaning of verse 36:36.

Conclusion

During the last three and a half billions years in the history of life, countless forms of biological organisms have evolved and perished. Of the small percentage of species that exist today, less than ten percent have so far been described in the scientific literature. Data gathered from these known species show that the majority of the sexually reproducing species employ such widely variable genetic mechanisms that a clear-cut evolutionary scheme of sex cannot be predicted. Understanding the origin of males and females among the known species, thus, seems to be a problem of a colossal scale. Gathering scientific data on the origin of males and females among

millions of existing species and among the extremely large number of unknown species appears to be an infinitely huge problem which appears to have been acknowledged in the Qur'ānic verse 36:36 by using a powerful statement "glory be to Him" in the beginning of the verse. However, only Allah (SWT) knows best the magnitude of this problem.

Appendix

Verse 36:36 contains a very serious statement where Allah (SWT) swears by His glory that He has created the males, females, and all the creatures that mankind may not know; yet, adequate, in-depth interpretations are lacking on this verse that could explain such importance. Of course, it is known that Allah (SWT) has emphasized similarly in the beginning of verse 17:1; and the importance of such a statement at the beginning of a verse is well understood from the unusual nature of the event (journey) stated in verse 17:1. From this point of view, one may rationally look for events of enormous nature that may also have been described in verse 36:36. Unfortunately, such an interpretation appears to be lacking in the Islamic literature. More surprisingly, it seems that the interpretation may have to come from science.

It also seems that the need for such an interpretation did not arise in the past because the scientific understanding of the origin of males and females was not clear until very recently. With the completion of human genome project (HGP), that scenario has changed drastically. Today, mankind possesses powerful scientific data and many have already started to exploit these HGP data in a way that radically challenges the fundamental truth described in Qur'ānic verse 36:36. In light of these newer scientific challenges, what one needs is to become familiar with a sound understanding of this verse by carefully examining the truth described in science and in the Qur'ān. In the foregoing discussion, the author intended to emphasize that the serious statement in the verse 36:36 could readily be understood when one realizes the intricate nature of the scientific problems involved in delineating the mechanism of the origin of sex. This analysis, therefore, has attempted to emphasize that the verse 36:36 may describe events of special nature; such understanding directly comes from science and somewhat indirectly from verse 17:1. Indirectly, because the verse 17:1 similarly starts with the statement "glory be to Him" and for which lengthy narrations are available.

The present analysis has primarily been aimed at utilizing the contemporary HGP data and other findings to get a more meaningful interpretation of powerful Qur'ānic verses like the verse 36:36. This analysis may, therefore, be of value to those academicians who like to Islamize their science curriculum or vice versa.

References

Agrawal, A. F. (2001). Sexual selection and the maintenance of sexual reproduction. *Nature* 411, 692-695.

Ali, S. and Hasnain, S. E. (2003). Genomics of the human Y-chromosome: 1. Association with male infertility. *Gene*, 321, 25-37.

Barton, N. H. and Charlesworth, B. (1998). Why Sex and Recombination? *Science*, 281(5385),

1986-1990.
Birky, C. W. (2005). Sex: Is Giardia Doing It in the Dark? *Current Biology*, 15(2), R56-R58.
Brasier, M. D., Green, O. R., Lindsay, J. F., McLoughlin, N., Steele, A. and Stoakes, C. (2005). Critical testing of Earth's oldest putative fossil assemblage from the 3.5 Ga Apex chert, Chinaman Creek, Western Australia. *Precambrian Research*, 140(1-2), 55-102.
Brent, D. G. (1991). *The Age of the Earth*. Stanford, Calif., Stanford University Press, 474 pp.
Bui E. T. N., Bradley P. J. and Johnson P. J. (1996). A common evolutionary origin for mitochondria and hydrogenosomes. *Proceedings of the National Academy of Sciences USA*, 93(18), 9651-9656.
Charlesworth, B. (1991). The evolution of sex chromosomes. *Science*, 251 (4997), 1030-1033.
Charlesworth, D. and Charlesworth, B. (2005). Sex Chromosomes: Evolution of the Weird and Wonderful. *Current Biology*, 15(4), R129-R131.
Coleman, D. C. and Whitman, W. B. (2005). Linking species richness, biodiversity and ecosystem function in soil systems. *Pedobiologia*, 49(6), 479-497.
Davison, J. (1999). Genetic Exchange between Bacteria in the Environment. *Plasmid*, 42(2), 73-91.
Doncaster, C. P., Pound, G. E. and Cox, S. J. (2000). The ecological cost of sex. *Nature,* 404, 281-285.
Graves, J. A. M., Koina, E. and Sankovic, N. (2006). How the gene content of human sex chromosomes evolved. *Current Opinion in Genetics & Development* (article in Press).
Graves, J. A. M. (2006). Sex Chromosome Specialization and Degeneration in Mammals, *Cell*, 124(5), 901-914.
Graves, J. A. M. (2002). Sex chromosomes and sex determination in weird mammals. *Cytogenetics and Genome Research*, 96: 161–168.
Green, R. F. and Noakes, D. L. G. (1995). Is a little bit of sex as good as a lot? *Journal of Theoretical Biology*, 174(1), 87-96.
Hoagland, K. E. (1978). Protandry and the evolution of environmentally mediated sex change: A study of the Mollusca. *Malacologia*, 17, 365-391.
Idler, D. R., Reinboth, R., Walsh, J. M. and Truscott, B. (1976). A comparison of 11-hydroxytestosterone and 11-ketotestosterone in blood of ambisexual and gonochoristic teleosts. *General and Comparative Endocrinology*, 30(4), 517-521.
Jablonka, E. (2004). The evolution of the peculiarities of mammalian sex chromosomes: An epigenetic view. *Bio-Essays*, 26(12), 1327-1332.
Jaccarini, V., Agius, L., Schembri, P. J. and Rizzo, M. (1983). Sex determination and larval sexual interaction in Bonellia viridis Rolando (Echiura: Bonelliidae). *Journal of Experimental Marine Biology and Ecology*, 66(1), 25-40.
Kohn, M., Kehrer-Sawatzki, H., Vogel, W., Graves, J. A. M. and Hameister, H. (2004), Wide genome comparisons reveal the origins of the human X chromosome. *Trends in Genetics*, 20(12), 598-603.
Kurtz, J. (2003). Sex, parasites and resistance—An evolutionary approach. *Zoology*, 106(4), 327-339.
Lahn, B. T. and Page, D. C. (1999). Four evolutionary strata on the human X chromosome. *Science,* 286(5441):877-9.
Lazcano, A., OróStanley, J. and Miller, L. (1983). Primitive Earth environments: organic syntheses and the origin and early evolution of life. *Precambrian Research,* 20(2-4), 259-282.
Liu, Z., Moore, P. H., Ma, H., Ackerman, C. M., Ragiba, M., Pearl, H. M., Kim, M. S., Charlton, J. W., Yu, Q., Stiles, J. I., *et al*. (2004). A primitive Y chromosome in Papaya marks the beginning of sex chromosome evolution. *Nature*, 427, 348-352.
Lobo, M. P. and Onody, R. N. (2006). Ploidy, sex and crossing over in an evolutionary aging model. *Physica A: Statistical Mechanics and its Applications*, 361(1), 239-249.
Marais, G. (2003). Biased gene conversion: Implications for genome and sex evolution, *Trends*

in Genetics, 19(6), 330-338.
McCall, G. J. H. (2006). The Vendian (Ediacaran) in the geological record: Enigmas in geology's prelude to the Cambrian explosion. *Earth-Science Reviews*, (in Press).
Michod, R. E. (1998). Origin of sex for error repair: III. Selfish sex. *Theoretical Population Biology*, 53(1), 60-74.
Neiman, M. (2004). Physiological dependence on copulation in parthenogenetic females can reduce the cost of sex. *Animal Behaviour*, 67(5), 811-822.
Odegaard, F. (2000). How many species of arthropods? Erwin's estimate revised, *Biological Journal of the Linnean Society*, 71(4), 583-597.
Pedrós-Alió, C. (2006). Marine microbial diversity: can it be determined? *Trends in Microbiology* (article in Press).
Ramesh, M. A., Malik, S-B. and Logsdon, J. M. (2005). A Phylogenomic Inventory of Meiotic Genes: Evidence for Sex in Giardia and an Early Eukaryotic Origin of Meiosis. *Current Biology*, 15(2), 185-191.
Ray, P. S. and Fox, P. L. (2005). Equality of the sexes: Found in translation. *Cell*, 122(4), 492-493.
Ridley, M. (2003). "The Red Queen: Sex and the Evolution of Human Nature". Harper Perennial Publishers, ISBN**:** 0060556579.
Riley, M. *et al*. (2006). *Escherichia coli* K-12: a cooperatively developed annotation snapshot—2005. *Nucleic Acids Research*, 34(1), 1-9.
Sarre, S. D., Georges, A. and Quinn, A. (2004). The ends of a continuum: Genetic and temperature-dependent sex determination in reptiles. *Bio-Essays*, 26(5), 639-645.
Smith, C. A. and Sinclair, A. H. (2004). Sex determination: Insights from the chicken. *Bio-Essays*, 26(2), 120-132.
Valley, C. M. and Willard, H. F. (2006). Genomic and epigenomic approaches to the study of X chromosome inactivation. *Current Opinion in Genetics & Development* (in Press).
Vyskot, B. and Hobza, R. (2005). Gender in plants: sex chromosomes are emerging from the fog. *Trends in Genetics*, 20(9), 432-438.
Waters, P. D., Duffy, B., Frost, C. J., Delbridge, M. L. and Graves, J. A. M. (2001). The human Y chromosome derives largely from a single autosomal region added to the sex chromosomes 80-130 million years ago. *Cytogenetics and Cell Genetics*, 92 (1-2), 74-79.
Waxman, D. and Peck, J. R. (1999). Sex and adaptation in a changing environment. *Genetics*, 153 (2), 1041-1053.
West, S. A. and Peters, A. D. (2002). Evolution: Paying for sex is not easy. *Nature* 407, 962.
Willard, C. L. (2005). X-inactivation profile reveals extensive variability in X-linked gene expression in females. *Nature* 434(7031), 400-4.
Yoshinaga, T., Kaneko, G., Kinoshita, S., Tsukamoto, K. and Watabe, S. (2003). The molecular mechanisms of life history alterations in a rotifer: a novel approach in population dynamics. *Comparative Biochemistry and Physiology* Part B: Biochemistry and Molecular Biology, 136(4), 715-722.
Zeyl, C. (2004). Experimental studies of ploidy evolution in yeast. *FEMS Microbiology Letters*, 233(2), 187-192.
Zhang, Y (2002). The age and accretion of the earth. *Earth-Science Reviews*, 59(1-4), 235-263.