第一课

同学们提的问题和建议，老帅回答，和选修的功课。

1. ‘道法自然’中的‘自然’应该是指‘自然而然，自己本来的样子’的意思。而不是翻译做 ’Nature’。

   回答：谢谢周一夫，赵辉，徐国梁对道德经的了解和评议，‘道法自然’ 应翻译为 “The law of the Tao is being what it is.” So, 道 is the law of the universe and everything in it, including the fusion plasma, device, technologies, components, and the entire fusion power plant. 这里‘自然’ 不应翻译为 “the nature”。

2. Elective homework is needed!

   回答：Agreed. See below.

3. How to develop a new design of tokamak, and where does your inspiration come from?

   回答：These are the topics I am also wondering about, and the answers will be multidimensional in nature. It is likely that the a few lectures during the Spring Semester will address these. In this case it would be very helpful if we start developing the next lower level questions that stems from these two questions.*

   选修的功课 20141114-1: Provide your answers to the following questions:

   a) What are the basic steps in design of a tokamak device, be it a near-term experiment or a future fusion nuclear power source?

   b) What could drive the need for a new (different from the well-known) design?

   c) What are the key differences between an inspiration and a technique (method) of a tokamak design?

4. Why is the plasma not axisymmetric in the picture (slide 6)?

   回答：This is due to the presence of a large-amplitude m=1, n=1 MHD kink mode with relatively minor destruction of magnetic flux surfaces. Here, m and n refer to the poloidal and toroidal mode number of the kink.

5. Is the losing of axisymmetry caused by turbulence?

   回答：Any $n\neq0$ mode in axisymmetric toroidal plasma would cause a loss of axisymmetry. Turbulence refers to a simultaneous presence of a range of large (m,n) modes, which would cause a loss of axisymmetry.

6. By what time do you think we can use the fusion power?

   回答：The Russian Acad. L.A. Artsimovich is said to have answered this question by saying something like: “Fusion power will be available when society wants it.”* I would add that society is made up of people. In 1956 he introduced for the first time the Tokamak configuration of magnetic confinement [*J. Nuclear Energy* **4** (1957) 203, translated by L.C. Ronson from *Atomnaya Energiya* **1** (1956) 76.], which catapulted the fusion world into the tokamak R & D today of a grand scale.

   选修的功课 20141114-2: In what ways does a society want fusion energy? In what ways is a society not yet ready for fusion energy? What do you think, as a fusion energy researcher, should think of doing to make fusion power available earlier rather than later?

7. What do you think about the news that Lockheed Martin Corporation saying that they can build a small fusion facility to generate power in 10 years?

   回答：There is no detailed information from the news nor the YouTube video on this subject. Various similar claims and sometimes funded efforts have occurred in recent years. We should look forward to learning from such efforts as they contribute to the progress of fusion energy R&D as a whole. It is also good to see that the society as a whole have shown rising interest in developing fusion energy at a faster pace than so far achieved.

8. Is MHD instability in a part of the plasma or the whole plasma in the picture (slide 6)?

   回答：In this case, the large kink mode is localized within about half of the plasma minor radius, though it also extends in small amplitude beyond this radius.

9. Why did we put more energy in the standard tokamak than in the spherical tokamak?

   回答：The purpose of introducing the spherical tokamak configuration was in part to increase plasma beta, the ratio of plasma thermal energy density over that of the magnetic field. As a result, the toroidal magnetic field applied to confine the plasma is reduced to a factor of 1/2 to below 1/3 for the same plasma content, dependent on the plasma aspect ratio (major radius over minor radius) in the range of 1.7 to 1.4. The stored toroidal field energy can therefore be reduced to 1/4 to 1/10 of that for a normal tokamak. Toroidal field magnets can be one of the largest cost factors of a normal tokamak. Assuming other factors being similar, this is one way in which the spherical tokamak requires less energy input than a normal tokamak.

   The subject is complex because a tokamak fusion energy system is a multidisciplinary complex system, requiring systems design analysis and optimization to more correctly compare normal tokamak and spherical tokamak designs.*

   ****选修的功课 20141114-3**: What are the major (5% or higher impact of total) cost drivers of the ITER project? What could possibly be considered that may have a potential to substantially the costs of these cost drivers?

10. What's the difference between single-null and double-null divertors? (You said you will give him some references, and his name is 黄燕青 and his email address is : yangqingh@mail.ustc.edu.cn)

    回答：To properly answer this question will require a couple of full lectures. It is appropriate to provide some recent references for the interested to read. I recommend the following reading to become aware of the major results and the bases for them:*

    a) Lee et al, *Nucl. Fusion* **41** (2001) 1515.

    b) Sabbagh et al, *Nucl. Fusion* **41** (2001) 1601.

    c) Counsell et al, *Plasma Phys. Control. Fusion* **44** (2002) 827.

    d) Eich et al, *Phys. Rev. Lett.* **91** (2003) 195003.

e) Labombard et al, *Nucl. Fusion* **44** (2004) 1047.

f) Saibene et al, *Nucl. Fusion* **45** (2005) 297.

g) Rice et al, *Nucl. Fusion* **45** (2005) 251.

h) Burrell et al, *Phys. Plasmas* **12** (2005) 056121.

i) Wu et al, *Fusion Engineering Design* **82** (2007) 463.

j) Pitts et al, *J. Nucl. Materials* **415** (2011) S957.

选修的功课 20141114-4: Find out and tabulate all significant science, engineering, and technology advantages and disadvantages of single-null versus double-null plasmas in tokamak designs.

11. In your opinion, is tokamak the best way to generate fusion power?

回答：Tokamak experiments have shown, at fusion practical densities (fractions of or above $10^{14}/cm^3$), superior electron confinement to allow very high thermal electron temperatures (up to hundreds of keV) among all toroidal confinement configurations. With such good confinement, the electrons at 10 keV would circulate the plasma torus along the field lines millions of time per second in ITER design. Thermal ions have shown even better confinement times than that of thermal electrons. So far, tokamak appears to be the only configuration with adequate data and understanding to predict long-time-duration, high-gain operations in D-T plasmas in ITER. For central power stations, where size of the power core is anticipated to be large,* the answer to this question would be in the affirmative, as far as getting to the "first base" is concerned.

"First base" is a metaphor from the game of baseball, where a player scores a point by successfully reaching the first, second, third, and home bases against opposing obstacles, whenever the ball is in transit. Loosely speaking, I would consider the first base to be burning plasma science, the second the engineering design and construction, the third the material and technology of fusion nuclear device and environment, and the home the economic viability and societal demand of fusion power.

选修的功课 20141114-5: Find out and tabulate the power core physical sizes and weights of coal-fire, natural gas-fire, and pressurized water nuclear power plants that produce 1000MW electricity. What further is the cost of the power core plus its supporting systems and equipment for these power plants, as fractions of the total power plant cost?

选修的功课 20141114-n, if submitted in 2 weeks from the date (yyyymmdd) will be reviewed and marked with comments for the student's benefit. Collaboration among students to do the homework is encouraged. The results of the submitted homework will help in composing good answers to the homework, to be posted 4 weeks from the date.