

PERFECT FLUID PROMOTION

Number of players: typically one, but speed and memory cubing competitions can be organized.

Object of the game: to solve a fully scrambled Perfect Fluid Promotion (PFP) on Rubik's 3x3 Cube by reaching its color-flavor-locked ground state.

The course of the game: The player inspects the thoroughly scrambled Perfect Fluid cube then put it back to the desk in front of them. They use the agreed method (both hands, or in extreme cases, single hand, both feet, blindfolded, underwater and so on) to solve the cube. By rotating the sides of the cube, they compete to restore the Perfect Fluid Cubes to the desired ground state.

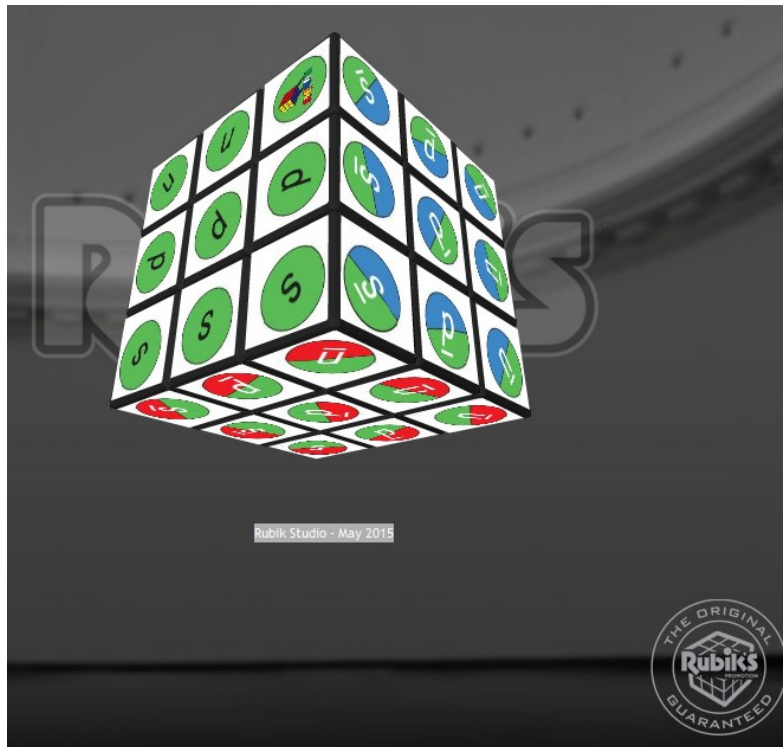


Figure 1. Perfect Fluid Promotion: Quark Matter on Rubik's 3x3 Cube. Credits and compliments are due to Rubik Studio Ltd. See the original promotion at <http://www.rubikanimations.com/cube/Perfect%20Fluid%20Cube?lang=en>.

The Quark Matter on Rubik's 3x3 – Perfect Fluid Promotion (PFP) game can be played at beginner, intermediate or advanced levels:

- 1) **On a beginner level,** players do not know the how to solve the standard Rubik's Cube. It is a challenging task to figure it on your own, but it is worth to try. Physicists or physics students are expected to be able to do the first layer on their own and some may even be able to do the second one. Doing all the three layers on his own lasted several weeks for Mr. Rubik himself, but these days there are several youtube videos that teach us how to solve the cube, see for example <https://www.youtube.com/watch?v=rmnSpUgOvyI>. This way the players will be able to solve the colors of the PFP cube. However, the orientation of the d-quarks on the center pieces on each face may still point to random directions.

- 2) **On an intermediate level**, the goal is to reach the color-flavor locked ground state. In this case, after the faces are color ordered, all the d quarks in the centers should point to the corner where red, green and blue colors meet, and all the anti-d quarks should point to the opposite corners, where the anti-red, the anti-green and anti-blue colors meet. This means that the players have to change the orientation of the center pieces on the faces of the cube without destroying the color order. This is also an already solved problem, sometimes referred to as solving the Super-Cube, custom-cube or picture-cube. Without significant cubing experience, physicists are not expected to figure this out on their own. To fix the direction of the centers, see e.g. <https://www.youtube.com/watch?v=fk1eCZNCTB4>.
- 3) **On an advanced level**, the players already know how to solve the Perfect Fluid Promotion Cube. But they can still improve the time they need to do so, they can try to do this blindfolded, by one hand, and use their feet, underwater or any other more or less mind-boggling method that are developed for the emerging arts of speed and memory cubing.

Some physics talking points:

1) **Quark Matter is a colorless state, but locally, colors are free, deconfined.** The PFP Cube is decorated by quarks and anti-quarks and illustrates a state of matter called Quark Matter or Perfect Fluid of Quarks, created in the first few microseconds after the Big Bang and reproduced in high energy heavy ion collisions at the RHIC accelerator at BNL, US and at the LHC accelerator near Geneva in Switzerland and France. The optical colors red, green and blue are used to model QCD color, an exact symmetry of the strong interactions. Quarks come in three different colors: red, green and blue. Antiquarks have anti-colors called anti-red, anti-green and anti-blue, represented by the combination of green/blue, blue/red and red/green colors, following the model developed for the Quark Matter Card Games [1]. In the ground state, the red face of the PFP is opposite to the anti-red, blue face is opposite to anti-blue, green is opposite to anti-green. In a random state of the PFP cube, locally the colors are not compensating each other to a red-green-blue that is a white combination, however, adding all the colors on the PFP cube results in an overall, globally white color for the Quark Matter.

2) **Flavor:** Quarks may have 6 different flavors, u, d, s, c, t and b. On this PFP cube, only the first three are utilized: u, d, and s. These quarks are most abundantly produced at RHIC and LHC. Can you order the faces of the PFP cube by the flavor? Why not?

3) **Quark Matter has a huge entropy density s.** This can be illustrated on the extremely large number of states on the PFP cube. When the 24 possible orientation of a given cube in space as well as all the possible orientation of the center pieces are taken into account, the possible number of states of the PFP Cube is increased from 88,580,102,706,155,225,088,000 (8.9×10^{22}) to 2,125,922,464,947,725,402,112,000 (2.1×10^{24}). Check the derivation of these huge numbers and evaluate the entropy density of the PFP Cube, knowing that the height of the cube is 57 mm.

4) **Estimate the kinematic viscosity η/s of the Perfect Fluid Cube.** Using the analogy of η , the viscosity coefficient for shear in the Navier-Stokes equation with the coefficient of friction when rotating a layer in the cube, estimate how far the PFP cube is from the conjectured quantum limit of $\eta/s \geq 1/(4\pi)$. Note: the torque needed to rotate a layer is of the order of 0.1 Nm.

Dedicated to the 2015 AGS and RHIC Users' Meeting and the 10th Anniversary of the Discovery of Perfect Fluid in Au+Au Collisions at RHIC. © 2015 by T. Csörgő, KRF, Gyöngyös, Hungary.

References:

[1] Judit Csörgő, Cs. Török, T. Csörgő:

Memory of Quark Matter Card Game, [arXiv:1303.2798](https://arxiv.org/abs/1303.2798) [physics.pop-ph]

[2] T. Csörgő, *Higgs Boson – on Your Own*,

In proc. EDS Blois 2013 conference, report no. EDSBlois/2013/54, [arXiv:1303.2732](https://arxiv.org/abs/1303.2732) [physics.pop-ph]

[3] T. Csörgő, *Perfect Fluid – Quark Matter on Rubik’s 3x3 Cube*,

talk at the WPCF 2014 conference and manuscript in preparation, <http://wpcf2014.karolyrobert.hu/>

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Available in the BERA Shop at BNL:

Limited number of Perfect Fluid Promotional Cubes are available at the BERA Shop in the Berkner Hall at BNL already during the 2015 AGS and RHIC Users Meeting.