Problems for the 37th IYPT 2024

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I hope we'll be able to solve these problems before we leave. – Pál Erdős

1. Invent Yourself
Take a box (e.g. a matchbox), filled with identical objects (e.g. matches, balls, ...). Find a method to determine the number of objects in the box solely by the sound produced while shaking the box. How does the accuracy depend on the properties of the objects, the box, and the packing density?

2. Droplet Microscope
By looking through a single water droplet placed on a glass surface, one can observe that the droplet acts as an imaging system. Investigate the magnification and resolution of such a lens.

3. Rigid Ramp Walker
Construct a rigid ramp walker with four legs (e.g. in the form of a ladder). The construction may begin to 'walk' down a rough ramp. Investigate how the geometry of the walker and relevant parameters affect its terminal velocity of walking.

4. Shooting Rubber Band
A rubber band may fly a longer distance if it is non-uniformly stretched when shot, giving it spin. Optimise the distance that a rubber band with spin can reach.

5. Ping Pong Rocket
A ping pong ball is placed in a container of water. When the container is dropped, the ping pong ball will get launched to a great height. What maximum height can you reach with up to 2 liters of water?

6. Non-contact Resistance
The responses of a LRC circuit driven by an AC source can be changed by inserting either a non-magnetic metal rod or a ferromagnetic rod into the inductor coil. How can we obtain the magnetic and electric properties of the inserted rod from the circuit's responses?

7. Giant Sounding Plate
When a large, thin and flexible plate (e.g. plastic, metal or plexiglass) is bent, it may produce a loud and unusual howling sound. Explain and investigate this phenomenon.

8. Another Magnetic Levitation
Place a large disk-shaped magnet on a non-magnetic conductive plate. When a smaller magnet is moved under the plate, the magnet on top may levitate under certain conditions. Investigate the levitation and the possible motion of the magnet on top.

9. Juicy Solar Cell
A functional solar cell can be created using conducting glass slides, iodine, juice (eg. blackberry) and titanium dioxide. This type of cell is called a Grätzel cell. Make such a cell and investigate the necessary parameters to obtain maximum efficiency.

10. Magnetic Gear
Take several identical fidget spinners and attach neodymium magnets to their ends. If you place them side by side on a plane and rotate one of them, the remaining ones start to rotate only due to the magnetic field. Investigate and explain the phenomenon.

11. Pumping Straw
A simple water pump can be made using a straw shaped into a triangle and cut open at the vertices. When such a triangle is partially immersed in water with one of its vertices and rotated around its vertical axis, water may flow up through the straw. Investigate how the geometry and other relevant parameters affect the pumping speed.

12. The Soap Spiral
Lower a compressed slinky into a soap solution, pull it out and straighten it. A soap film is formed between the turns of the slinky. If you break the integrity of the film, the front of the film will begin to move. Explain this phenomenon and investigate the movement of the front of the soap film.

13. Charge Meter
A lightweight ball is suspended from a thread in the area between two charged plates. If the ball is also charged it will be deflected to one side at a certain angle. What is the accuracy of such a device for measuring the amount of charge on the ball? Optimise your device to measure the smallest possible charge on the ball.

14. Ruler Trick
Place a ruler on the edge of a table, and throw a ball at its free end. The ruler will fall. However, if you cover a part of the ruler with a piece of paper and repeat the throw, then the ruler will remain on the table while the ball will bounce off it. Explain this phenomenon, and investigate the relevant parameters.

15. Wet Scroll
Gently place a piece of tracing paper on the surface of water. It rapidly curls into a scroll and then slowly uncurls. Explain and investigate this phenomenon.

16. Cushion Catapult
Place an object on a large air cushion and drop several other objects in such a way that the first object is catapulted away. Investigate how the exit velocity depends on relevant parameters.

17. Quantum Light Dimmer
If you put a flame with table salt added in front of a vapour sodium lamp, the flame casts a shadow. The shadow can become lighter, if the flame is put into a strong magnetic field. Investigate and explain the phenomenon.

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CUPT2024 中(英)文版赛题与浅析

01/ Invent Yourself /自己发明

Take a box (e.g. a matchbox), filled with identical objects (e.g.matches, balls, …). Find a method to determine the number of objects in the box solely by the sound produced while shaking the box. How does the accuracy depend on the properties of the objects, the box, and the packing density?

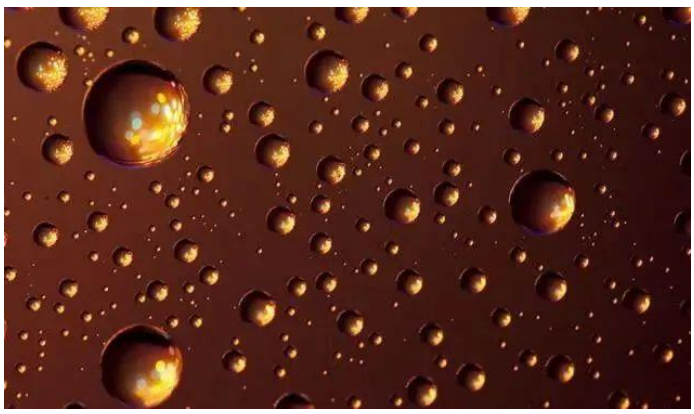
考虑一个装满相同物体（如火柴、球）的盒子（如火柴盒），找到一种方法来仅通过晃动盒子时产生的声音来确定盒子中物体的数量。这种方法的准确性如何取决于物体的性质、盒子的性质和装填密度？

02/ Droplet Microscope /液滴显微镜

By looking through a single water droplet placed on a glass surface, one can observe that the droplet acts as an imaging system. Investigate the magnification and resolution of such a lens.

透过一滴放置在玻璃表面的水滴观察，可以发现水滴能充当一种成像系统。研究这种透镜的放大率和分辨率。

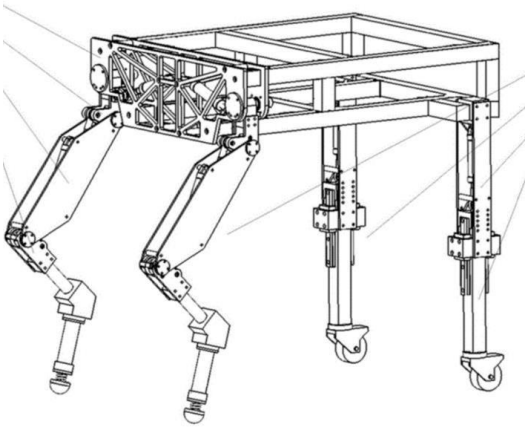
浅析：本题的研究分为两步。第一步确定玻璃板上液滴形状，这完全由液滴的体积和与接触面的表面张力系数确定。确定液滴形状后，剩下的研究就是标准的几何光学问题：研究这一几何形状（液滴表面几何）的厚透镜成像规律，放大率和分辨率在光学中有标准的定义。



03/Rigid Ramp Walker /刚性斜面行走器

Construct a rigid ramp walker with four legs (e.g. in the form of a ladder). The construction may begin to ‘walk’ down a rough ramp. Investigate how the geometry of the walker and relevant parameters affect its terminal velocity of walking.

搭建一个有四条腿的刚性斜面行走器（如梯子的形式），此结构可以在粗糙的斜面上向下“行走”。研究行走器的几何特征及相关参数如何影响其行走的最终速度。

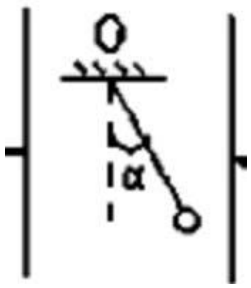


浅析：简单地行走机器人，分为主动和被动的构型。本题提到的是沿着斜面向下走，应该是将重力势能转化为动能的被动行走机器人。本部分研究在行走机器人领域有充分的研究基础，可以参考的文献较多[如 刘玉刚. 准四足被动行走机器人的动力学仿真研究[D].哈尔滨工业大学,2012.]。建议先对已有的研究和基本结构有充分的了解再进行实验探索。理论分析部分，可以将机器人行走分为质心运动和每只足的绕定点或者定轴转动，结合刚体转动和质点系运动进行研究。

04/ Charge Meter /电荷测量计

A lightweight ball is suspended from a thread in the area between two charged plates. If the ball is also charged it will be deflected to one side at a certain angle. What is the accuracy of such a device for measuring the amount of charge on the ball? Optimise your device to measure the smallest possible charge on the ball.

一个轻质小球通过一根线被悬挂在两个带电板之间。如果球也带电，它会以一个特定的角度被偏转到一侧。这种测量小球带电量的装置的精度是多少？优化你的装置用于测量球上可能的最小电荷。

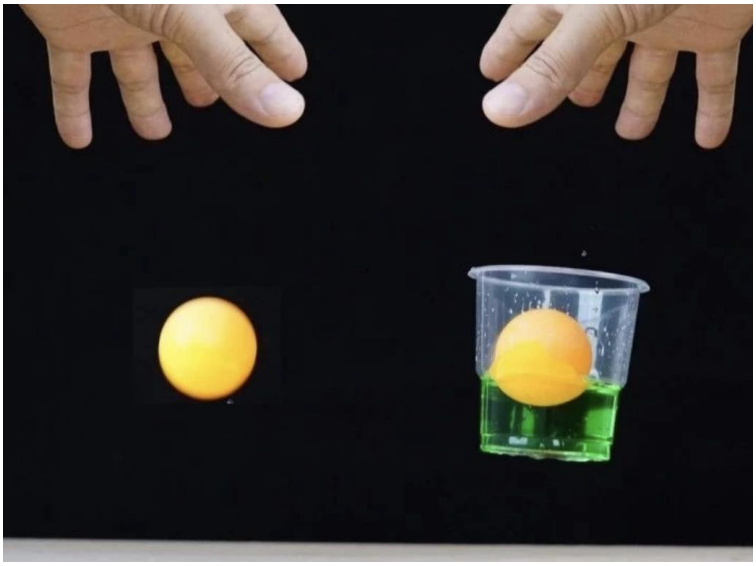


浅析：本文的力学基础很简单，点电荷在匀强电场（近似）中的平衡。显然不同电荷量的小球会偏转的角度不同（角度由小球受到的电场力和重力的比例确定），若需要对电荷测量尽可能灵敏，则需要电荷变化后角度的响应足够灵敏。理论上用偏导关系得到电荷关于角度的误差传递公式来分析这一灵敏度是非常直接的。实验上，本题目的量化和测量都比较简单。

05/ Ping Pong Rocket /乒乓球火箭

A ping pong ball is placed in a container of water. When the container is dropped, the ping pong ball will get launched to a great height. What maximum height can you reach with up to 2 liters of water?

一个乒乓球放置在装水的容器中，当容器被释放时，乒乓球会发射到一个很高的高度。使用 2 升水最高能达到多少高度？



浅析：一个经典的能量转换实验。在受到撞击后，液体会像中间聚集，中部液体向上快速弹起将动能传递给乒乓球，乒乓球质量小从而获得较大动能后以较大初速度弹起，进而弹起较高高度。本问题中给定的参数是水的体积，简单来想优化的目标就是容器形状。最简单的考虑，容器都是圆柱体，则可以自然地问：圆柱内液体体积固定，是半径大的圆柱好还是瘦长的圆柱好（让乒乓球弹起更高）？这部分研究需要建立液体动能向乒乓球传递的定量关系式，然后分析乒乓球获得动能大小对液体初始半径、高度的依赖关系后，确定具体优化方式。

06/ Non-contact Resistance /非接触电阻

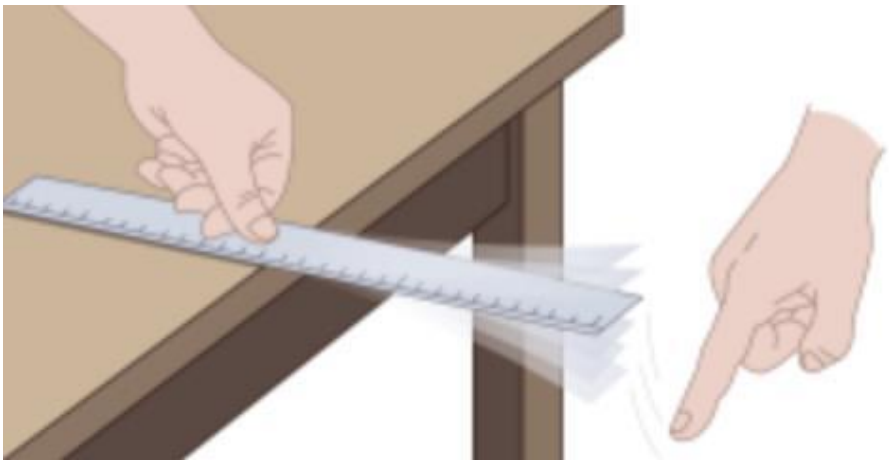
The responses of a LRC circuit driven by an AC source can be changed by inserting either a non-magnetic metal rod or a ferromagnetic rod into the inductor coil. How can we obtain the magnetic and electric properties of the inserted rod from the circuit’s responses?

交流电源驱动的 LRC 电路响应可通过在电感线圈中插入非磁性金属杆或铁磁杆来改变。如何从电路的响应中得到插入杆的电磁特性？

07/ Giant Sounding Plate /大型发声板

When a large, thin and flexible plate (e.g. plastic, metal or plexiglass) is bent, it may produce a loud and unusual howling sound. Explain and investigate this phenomenon.

一个大的、薄的、柔韧的板（如塑料板、金属板或有机玻璃）被弯曲时，会发出响亮且不同寻常的呼啸声。解释并研究此现象。



08/ Another Magnetic Levitation /另一个磁悬浮

Place a large disk-shaped magnet on a non-magnetic conductive plate. When a smaller magnet is moved under the plate, the magnet on top may levitate under certain conditions. Investigate the levitation and the possible motion of the magnet on top.

将一个大的圆盘状磁铁放在非磁性的导电板上。当一个较小的磁铁在板的下方移动时，顶部的磁铁在一定条件下可能会悬浮。研究顶部磁铁的悬浮和可能的运动。

09/ Juicy Solar Cell /果汁太阳能电池

A functional solar cell can be created using conducting glass slides, iodine, juice (eg. blackberry) and titanium dioxide. This type of cell is called a Grätzel cell. Make such a cell and investigate the necessary parameters to obtain maximum efficiency.

一个功能性的太阳能电池可以使用导电玻璃片、碘、果汁（例如黑莓）和二氧化钛来制做。这种类型的电池被称为 Grätzel 电池。制作这样的电池并研究获取最大效率所需的参数。

浅析：利用生化反应的水果电池是常见的中小学科创实验。本题的水果电池不同寻常，是水果果汁参与制作太阳能电池。实际上，20 世纪 90 年代，Brian O'Regan 和 Michael Grätzel 发明了介观染料敏化太阳能电池（DSCs），这就是著名的 Grätzel 电池。DSCs 通过光敏剂将光转换成电。这些是吸收光的染料化合物，并将电子注入氧化物纳米晶体阵列中，随后以电流形式收集。从背景来看，果汁可以起到这种电池中所需燃料的作用。

10/ Magnetic Gear /磁力齿轮

Take several identical fidget spinners and attach neodymium magnets to their ends. If you place them side by side on a plane and rotate one of them, the remaining ones start to rotate only due to the magnetic field. Investigate and explain the phenomenon.

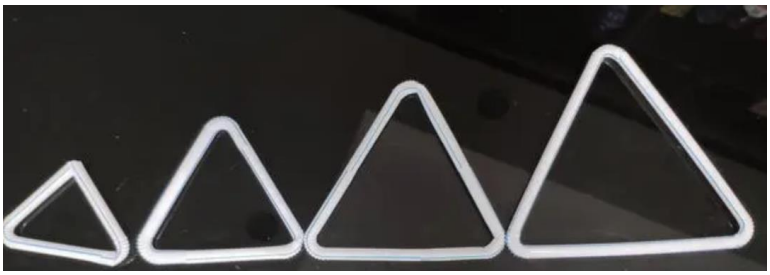
取几个相同的指尖陀螺，并将钕磁铁固定在它们的末端。如果将它们并排放置在平面上并旋转其中一个陀螺，则其余的陀螺会仅由于磁场而开始旋转。研究并解释这一现象。

浅析：本题的现象很容易想到。本来独立运动的指尖陀螺，因为端点所放置磁铁的相互吸引（排斥）而产生了耦合运动。第一个转动陀螺的动能因为这一耦合将能量传递的其它陀螺。本问题中，能量转移的速率，是否具有周期性，会不会出现拍频，以及体系陀螺的个数如何影响上述几点是值得研究的方向。

11/ Pumping Straw/吸管水泵

A simple water pump can be made using a straw shaped into a triangle and cut open at the vertices. When such a triangle is partially immersed in water with one of its vertices and rotated around its vertical axis, water may flow up through the straw. Investigate how the geometry and other relevant parameters affect the pumping speed.

一个简单的水泵可以将一根吸管折成三角形，并在顶点处切开的方式来制作。当这样一个三角形部分浸入水中，其中一个顶点绕其三角形的竖直轴旋转时，水可能会通过吸管流向上方。研究几何形状和其他相关参数如何影响泵水的速度。



浅析：本问题的关键是所设计的简单水泵将水泵至高处的压力来源。题目所描述过程已经提示我们，这一压力来源是旋转。简单思考便知，是因为旋转导致习惯中水受到的离心力通过管子的特殊弯折（三角形）将水压至上方。本问题中，转速和几何形状（三角形的特征）如何影响泵水速度是需要讨论的核心。

12/ The Soap Spiral /肥皂螺旋

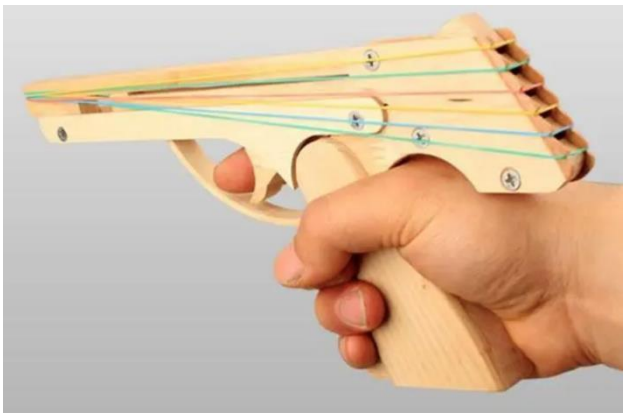
Lower a compressed slinky into a soap solution, pull it out and straighten it. A soap film is formed between the turns of the slinky. If you break the integrity of the film, the front of the film will begin to move. Explain this phenomenon and investigate the movement of the front of the soap film.

将一个压缩的螺旋弹簧玩具（slinky, 俗名彩虹圈）放入肥皂溶液中，把它拿出来并拉直。弹簧的圈之间就形成了一个肥皂膜。如果你破坏了肥皂膜的完整性，肥皂膜的前端就会开始移动。解释这个现象，并研究肥皂膜前端的运动。

13/ Shooting Rubber Band /发射橡皮筋

A rubber band may fly a longer distance if it is non-uniformly stretched when shot, giving it spin. Optimise the distance that a rubber band with spin can reach.

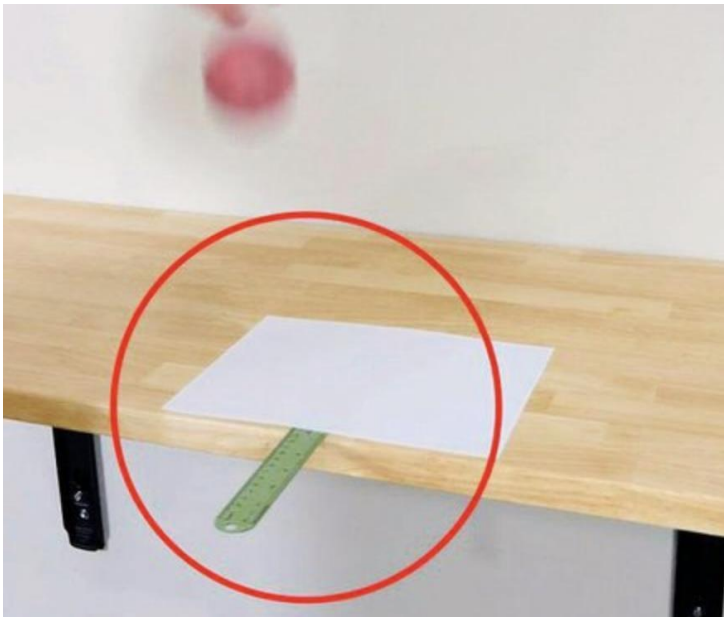
如果橡皮筋在发射时被不均匀拉伸而使其旋转，它可能会飞行更远的距离。优化带有旋转的橡皮筋可以到达的距离。



14/ Ruler Trick /尺子把戏

Place a ruler on the edge of a table, and throw a ball at its free end. The ruler will fall. However, if you cover a part of the ruler with a piece of paper and repeat the throw, then the ruler will remain on the table while the ball will bounce off it. Explain this phenomenon, and investigate the relevant parameters.

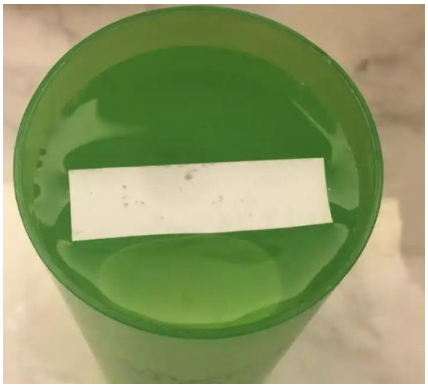
将一把尺子放在桌子边缘，然后将一个球投向尺子的自由端。尺子将会落下。然而，如果你用一张纸盖住尺子的一部分并重新投掷小球，那么尺子将保留在桌子上，而球会从尺子上弹开。解释这一现象，并研究相关参数。



15/ Wet Scroll /湿纸卷

Gently place a piece of tracing paper on the surface of water. It rapidly curls into a scroll and then slowly uncurls. Explain and investigate this phenomenon.

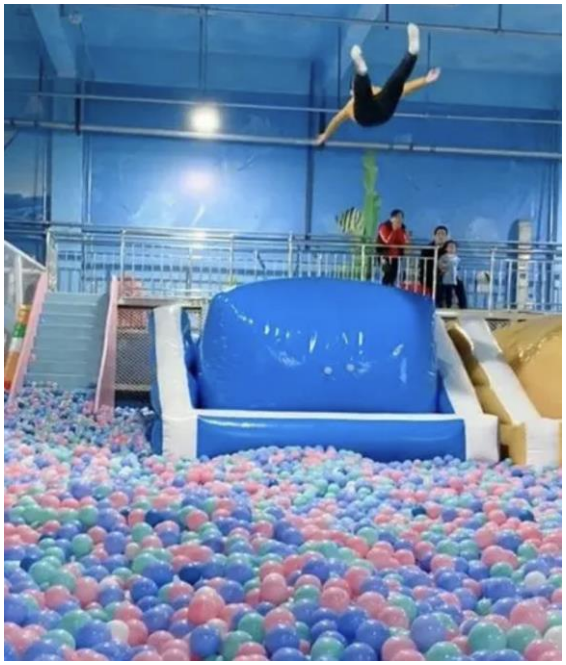
将一张描图纸轻轻地放在水面上。它会迅速卷曲成一纸卷，然后慢慢展开。解释并研究这个现象。



16/ Cushion Catapult /气垫弹射器

Place an object on a large air cushion and drop several other objects in such a way that the first object is catapulted away. Investigate how the exit velocity depends on relevant parameters.

将物体放置在一个大的气垫上，然后丢下几个其他物体，第一个物体会被弹射出去。研究弹射速度与相关参数的关系。

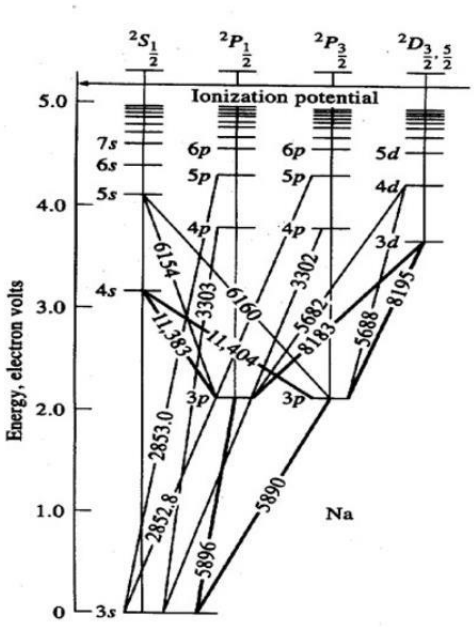


浅析：本题目涉及的研究来源于一种很火的游戏，一个人躺在气垫或者弹簧床上，多个人跳上去可以将躺着的人弹起至很高的地方。本问题也是一种能量转换机制，气垫是多个物体动能向单个物体转换的媒介，需要考虑气垫的压强，尺寸等对该能量转换率（弹起物体动能与多个物体接触气垫的动能的比）的影响。弹射物体的弹射速度直接由能量转换率确定。

17/ Quantum Light Dimmer /量子光调节器

If you put a flame with table salt added in front of a vapour sodium lamp, the flame casts a shadow. The shadow can become lighter, if the flame is put into a strong magnetic field. Investigate and explain the phenomenon.

如果在蒸汽钠灯前放置加入了食盐的火焰，火焰会投下阴影。如果火焰放置在一个强磁场中，阴影会变得更亮。研究并解释此现象。



浅析：本题涉及到量子物理中原子能级的知识。我们知道，火焰会有阴影的原因是因为钠光灯发出的光被火焰中的氯化钠蒸汽部分吸收导致的。加强磁场后，钠的能级会因为磁场出现塞曼劈裂，从而使得火焰对无磁场中钠所发出特定波长光的吸收率降低，进而使得透过的光增加阴影变亮。该问题的定量分析需要量子物理的理论基础，实验部分探究磁场强度如何影响最终透光量是一个定量的可能方向。