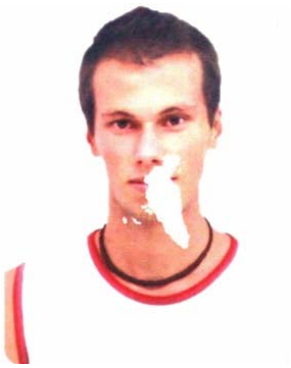
INSTRUMENTAÇÃO PARA O ENSINO - F 809

RELATÓRIO FINAL DE ATIVIDADES

FONTE DE HERON



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CAMPINAS, 23 DE NOVEMBRO DE 2006.

1 RESUMO

Os princípios que foram abordados neste experimento mostram que recipientes conectados colocados em alturas diferentes produzirão diferenças de pressões internas nos recipientes, o que pode proporcionar um chafariz operando sem baterias elétricas ou algum tipo de entrada de energia, apenas com a força exercida pela gravidade. O trabalho desenvolvido neste projeto, consistiu na construção de uma Fonte de Heron, com o uso de materiais de fácil acesso e de baixo custo, onde esta fonte funciona sem uso de motores ou bombas, o que pode ser utilizado em conjunto com uma aula teórica nos ensinamentos dos Princípios e Leis da Hidrodinâmica e Hidrostática.

2 INTRODUÇÃO

Heron foi um grande engenheiro, matemático e físico. Acredita-se que Heron viveu em torno de 10 a 70 d.C., mas há relatos também de que seja entre 20 a 62 d.C..Ele era conhecido também como Hero ou Heron de Alexandria. Hero deixou grandes invenções e contribuições nas ciências exatas tais como: foi o primeiro inventor a documentar o motor movido a vapor e também a "aeolipile" (aparato que funciona como uma bobina através de vapor), além de ter deixado a conhecida Fórmula de Heron usual para calcular a área de um triângulo em termos de seus lados. Também contribuiu na astronomia onde forneceu o método computando a distâncias entre Roma e Alexandria através da hora local do eclipse lunar.

Além de todas esses legados deixados por ele houve um em especial que nos dedicamos em reproduzi-lo. O aparato leva o nome de Fonte de Heron. Esta fonte descrita por Heron de Alexandria era um instrumento razoavelmente popular nas coleções além de servir muitas vezes de enfeite até o começo do século XX e agora será usada como um instrumento de auxílio didático.

3 DESCRIÇÃO

A princípio a fonte parece uma máquina perpetua, mas observando melhor percebe-se que não passa de um simples aparato que por diferença de energia potencial entre as garrafas causa um fluxo do líquido de um reservatório para outro fazendo com que ocorra um chafariz.

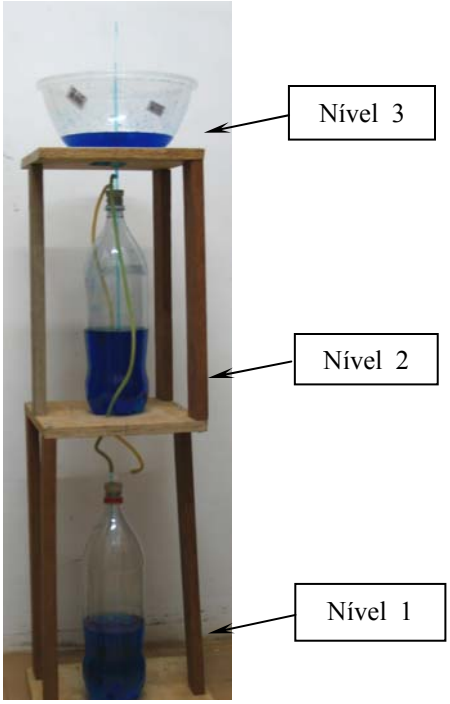


Figura 1: Fonte de Heron.

4 PRINCÍPIO DE FUNCIONAMENTO DA FONTE

1. A princípio colocamos uma certa quantidade de líquido no pote na parte superior da fonte (nível 1) para ativarmos seu funcionamento. A quantidade de líquido adicionado no pote regula a quantidade de tempo com que a fonte fica funcionando e também a altura máxima que o chafariz pode atingir. Através de um furo numa rolha acoplada ao pote, onde há um cano embutido, o líquido desce até a garrafa do nível 1.

2. O líquido vai descendo por um dos canos até a garrafa do nível 1 que inicialmente estava vazia. O líquido vai enchendo a garrafa e expulsando o ar que sai por outro cano até a garrafa de cima (nível 2), que está cheia de líquido. A medida que a garrafa do nível 3 vai enchendo a pressão interna vai aumentando fazendo com que o ar seja expulso apenas por outro orifício acoplado com um cano. A garrafa foi vedada através de uma rolha para evitarmos muitas perdas de pressão e nisso fizemos dois furos na rolha onde os canos são acoplados.

3. O ar expulso da garrafa do nível 1 vai entrando na garrafa de cima e com isso há aumentando da pressão interna da garrafa do nível 2 fazendo com que o líquido desta seja deslocado por outro cano. Conseqüentemente o líquido é forçado a subir até a parte de cima (menor pressão) através de outro cano, passando através do pote, sem nenhuma interferência com o líquido do pote, e sendo jorrando por um caninho, formando um chafariz.

4. Assim que o líquido sai pelo caninho e cai no pote do nível 3 ele começa a encher novamente o pote e através do mesmo cano com que o líquido deslocou-se até o nível 1 o líquido retorna novamente por ele até a garrafa do menor nível (nível 1) e assim o ciclo recomeça novamente.

Assim a fonte funcionará até que todo o líquido presente na garrafa do nível 2 se esgote. Para um novo funcionamento da Fonte de Heron deve-se novamente encher a garrafa do nível 3 e esvaziar a do nível 2, e isto é feito manualmente. Para que não haja desperdício de líquido e também não ocorra sujeira, a garrafa do nível 2 é uma garrafa Pet de 2 litros que não foi completamente cheia e a do nível 3 é uma de 2,5 litros. Esses dois volumes diferentes e o não enchimento completo da garrafa (2l) devem-se ao fato de que ao enchermos o pote do nível 3 com líquido, este e mais o da garrafa do nível 3, serão escoados para a garrafa do nível 1, por isso o seu volume maior e também o não enchimento por completo da garrafa do nível 2. Se colocássemos o volume completo de líquido na garrafa do nível 2, mais os volumes do pote (o volume do pote foi variado de 300 a 800ml) ao final do experimento teriam algumas vezes (dependendo do volume de líquido utilizados no nível 3) um volume de líquido maior com que a garrafa suporta e conseqüentemente o líquido ficaria dentro dos capilares e na hora de desmontarmos o experimento o esse seria derramado causando um desperdício e uma má impressão do experimento, não se tornando prático.

5 RESULTADOS E DISCUSSÕES

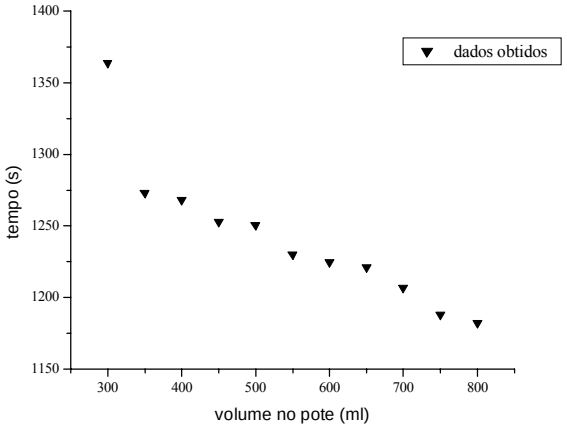
A medida que variávamos a quantidade de líquido no pote a fonte mudava o tempo com que ficava funcionando e também a altura do chafariz. Sabendo disso variamos a quantidade de líquido adicionado ao pote do nível 1 a fim de fazer uma estimativa do tempo que a fonte poderia ficar funcionando. Na Tabela 1 está indicado o volume adicionado de líquido juntamente com o tempo e a altura máxima do chafariz.

Tabela 1: Volume de líquido adicionado no pote, tempo que a fonte ficou funcionando e a altura máxima atingida pelo líquido. (1200s = 20minutos)

vol. no pote (ml)	tempo(s)	altura máx. (cm)
300	1364	23
350	1273	24
400	1268	24
450	1253	24.5
500	1251	25
550	1230	25
600	1225	25.5
650	1221	26
700	1207	26.5
750	1188	26
800	1182	26

Pela Tabela 1 temos que a fonte funcionava com um tempo bastante bom (cerca de 20 minutos). Dentro dos três primeiros minutos a fonte jorra o líquido de uma forma uniforme, podendo chegar em alguns volumes até uma altura 26,5cm contados apartir da base do nível 3. Depois disso, até cerca de 10 minutos de funcionamento, há uma maior queda dessa uniformidade (começa a oscilar a altura do líquido) e nos minutos seguintes a fonte não apresenta um chafariz de tamanho tão grande quanto nos minutos iniciais.
Com a tabela acima foi possível montar os Gráficos 1 e 2 mostrados abaixo:

Gráfico 1: Tempo de funcionamento da fonte versus volume adicionado ao pote.

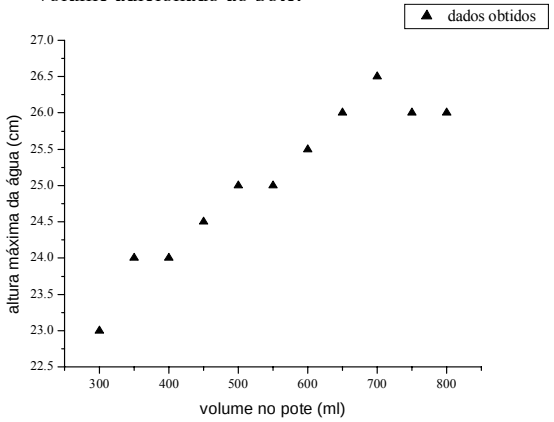


Podemos notar pelo gráfico acima que a medida que o volume do pote era aumentado o tempo com que a fonte funcionava era menor, o fato disso ocorrer era que aumentando a altura da coluna de líquido (*H*) a pressão exercida na garrafa do nível 1 aumenta fazendo

com que o ar seja expulso mais rapidamente. Se não houvesse perdas nossa fonte jorraria o líquido até uma altura *H* ao invés de uma altura *h* como mostrado na Figura 2. Essa seria a altura máxima que nossa fonte chegaria e com isso a velocidade ao final dessa altura seria zero.

Além do Gráfico 1 também se obteve o Gráfico 2.
Podemos notar que a medida que o volume de líquido no nível 3 é aumentado a pressão aumenta e a altura com que o líquido é esguichado também aumenta.

Gráfico 2: Altura máxima atingida pelo líquido versus volume adicionado ao pote.



Para calcular a velocidade com que o líquido era ejetado do chafariz propusemos alguns métodos que serão descritos abaixo:

5.1 MÉTODO I

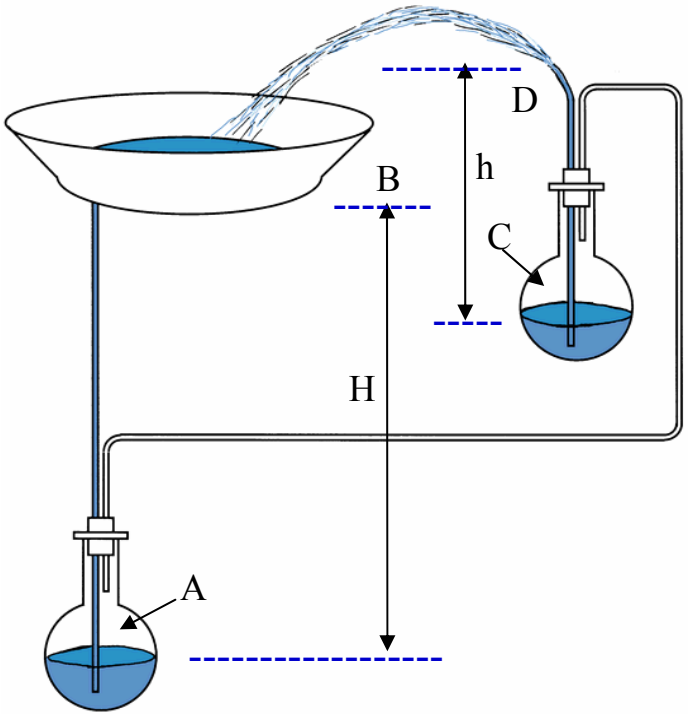


Figura 2 : Esboço da Fonte de Heron.

$$P_A = P_{atm} + \rho g H \quad (1)$$

onde P_{atm} é a pressão atmosférica em B (nível 3);
ρ é a densidade do líquido;
g a aceleração da gravidade;
H é a altura da coluna de líquido e
P_A é a pressão em A (nível 1)
Com isso a medida que o volume de líquido adicionado no nível 3 é aumentado e conseqüentemente a altura H aumenta (relação não linear devido ao formato do pote), a pressão exercida na garrafa do nível 1 também aumenta.
Conseqüentemente ao subir o nível de líquido em A, a pressão em C (nível 2) sobe acima do valor inicial ($P_{atm} + \rho g h$) o que força a água sair.
Pelo Princípio de Pascal sabemos que a pressão do ar em A será igual em C e a pressão ao final do chafariz (D) é dada por:

$$P_D = P_{atm} + \rho g (H - h) \quad (2)$$

Pela equação de Bernoulli podemos encontrar a velocidade com que o líquido escoa pelo chafariz (a equação da velocidade foi deduzida no relatório parcial).

$$v = \sqrt{2g(H - h)} \quad (3)$$

Temos que a altura H no começo é 90.6cm e que h é 34.5cm. Ao decorrer do experimento a altura h varia e portanto calcularemos apenas a velocidade máxima por esse método. Com isso podemos encontrar a velocidade máxima que o líquido sobe pelo chafariz.

$$v_{max} \approx 300\text{cm/s}$$

Apesar das perdas devido a turbulência, a resistência do ar na saída do tubo, atrito, elasticidade dos tubos e das garrafas, perda de pressão etc e tentaremos chegar o mais próximo possível dessa velocidade com nossa fonte.

5.2 MÉTODO II

Outra maneira de calcularmos a velocidade de saída do líquido foi colocar uma régua de 10cm numa parte da garrafa do nível 2 aproximando-a por um cilindro de diâmetro 98,8mm. Com isso a medida que o líquido abaixava de 0,5cm anotávamos o tempo parcial, obtendo uma velocidade e conseqüentemente uma velocidade de saída do chafariz. As medidas foram feitas entre a marca de 8,5cm a 0 da régua, onde a garrafa era aproximadamente um cilindro e a medida que a altura abaixava o tempo era marcado obtendo a Tabela 2.

Tabela 2: Altura do líquido na garrafa com os tempos parciais e o tempo total decorrido.

altura (cm)	tempo parcial(s)	tempo total (s)
8.5	0	0
8	19.92	19.92
7.5	23.36	43.28
7	24.17	67.45
6.5	20.2	87.65
6	20.49	108.14
5.5	24.59	132.73
5	23.92	156.65
4.5	21.8	178.45
4	25.37	203.82
3.5	22.07	225.89
3	26.03	251.92
2.5	22.51	274.43
2	27.94	302.37
1.5	23.89	326.26
1	27.86	354.12
0.5	23.78	377.9
0	28.55	406.45

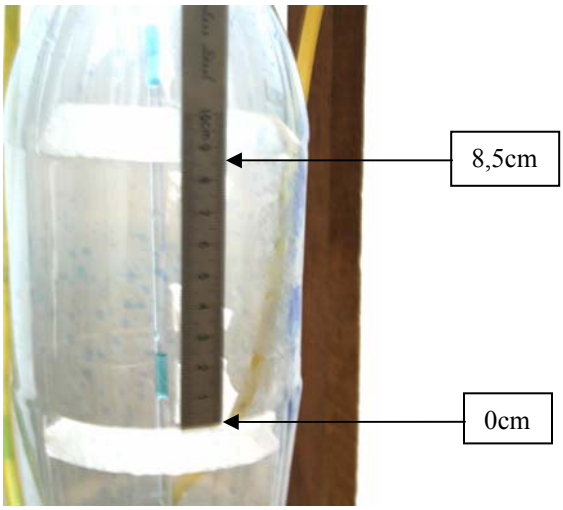
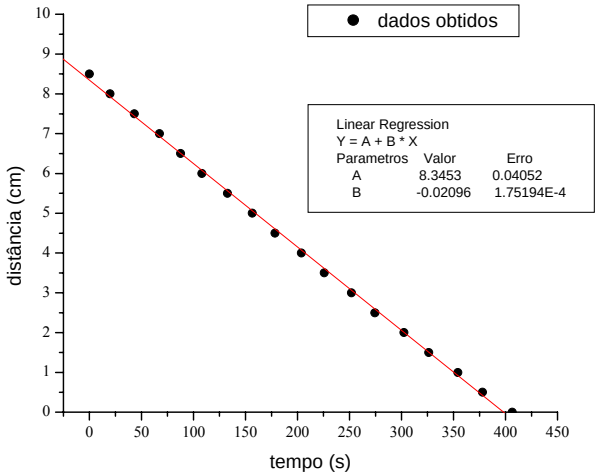


Figura 3: Garrafa do nível 2 com uma régua.

Pela tabela acima podemos plotar um gráfico da altura na régua em função do tempo.
Pelo Gráfico 3 podemos notar que a coluna de líquido desce com uma velocidade aproximadamente constante.

Gráfico 3: Altura da coluna de líquido (distância) pelo tempo.



Através do gráfico acima calcularemos a velocidade de descida e subida do líquido, o que será feito mais abaixo. Como sabemos a distancia percorrida pelo líquido na garrafa, o tempo que ele demorou para percorrer e também que a quantidade de líquido que sai da garrafa é a mesma que foi expelida pelo chafariz, pode-se encontrar a velocidade com que o líquido sai (**v_{sobe}**).

O volume que desce de líquido é o mesmo que sobe ($V_{desce} = V_{sobe}$). Sabendo que o volume é a área multiplicada pela altura com que o líquido desce ($V = A \cdot h$) e dividindo esse volume pelo tempo, temos que $\frac{V}{t} = A \cdot \frac{h}{t} = A \cdot v$, onde ν é a velocidade.

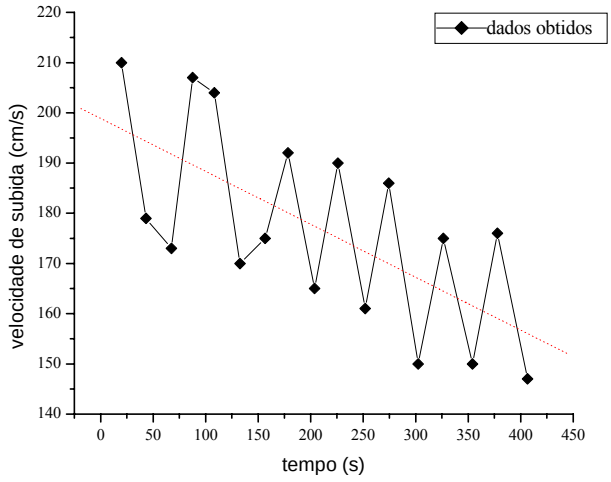
Quando o líquido de dentro da garrafa passa para o capilar a velocidade aumenta, então podemos calcular essa velocidade com que o líquido sai. Medindo a área da garrafa (A_0 = 7666,61 mm^2) e também a área do capilar (A = 0,916mm^2), temos a velocidade com que o líquido é esguichado do chafariz ($v_{desce} A_0 = v_{sobe} A$), como mostrado na Tabela 3:

Tabela 3: Tempo com que o líquido percorreu a distancia marcada e as velocidades do líquido na garrafa (ν_{desce}) e no capilar.(ν_{sobe}).

tempo total (s)	ν_{desce} (cm/s)	ν_{sobe} (cm/s)
0	-	-
19.92	0.0251	210.06
43.28	0.0214	179.13
67.45	0.0207	173.12
87.65	0.0248	207.15
108.14	0.0244	204.22
132.73	0.0203	170.17
156.65	0.0209	174.93
178.45	0.0229	191.95
203.82	0.0197	164.94
225.89	0.0227	189.60
251.92	0.0192	160.75
274.43	0.0222	185.89
302.37	0.0179	149.76
326.26	0.0209	175.15
354.12	0.0179	150.19
377.9	0.0210	175.96
406.45	0.0175	146.56

Com a Tabela 3 acima pode-se plotar o Gráfico 4.

Gráfico 4: Velocidade de subida do líquido no chafariz pelo tempo.



Pelo gráfico acima podemos notar que a velocidade vai diminuindo um pouco a medida que o tempo passa e conseqüentemente a fonte começa a perder altura no chafariz. Nota-se que a velocidade da fonte além de diminuir ela se mostra oscilatória, devido a turbulência, pressão não constante* etc.
Uma maneira de calcular a velocidade é através do coeficiente angular da reta encontrada no Gráfico 3. Pelo coeficiente obtivemos $\mathbf{v}_{desce}$ = 0,021cm/s e conseqüentemente a velocidade com que o líquido sobe é $\mathbf{v}_{sobe}$ = 176cm/s.

Como sabemos a altura que o líquido desce na garrafa e portanto sabemos o volume, podemos estimar a vazão da fonte de Heron. Sabendo que a vazão é dada como volume pelo tempo e que isso também é a área multiplicada pela velocidade (vazão $= \frac{V}{t} = A \cdot \frac{h}{t} = A \cdot v$) encontramos a vazão da fonte.
Vazão = A . v = 76,67cm^2 . 176cm/s = 13,476 x 10^3 cm^3/s
Portanto temos que a vazão da nossa fonte é em média 0,0135m^3/s

*A pressão não constante é devido ao diâmetro não uniforme dos tubos, elasticidade dos tubos de borracha, bolhas de ar no líquido etc.

6 CONCLUSÃO

Com nossa fonte pudemos encontrar dois valores de velocidade, uma experimental e outra teórica. Apesar dos resultados estarem um pouco distantes ($v \approx$ 300cm/s (teórico), $v \approx$ 176cm/s), podemos dizer que nossa Fonte de Heron foi construída com sucesso, pois aparentemente não nos mostra grandes problemas. Esta fonte pode ser muito bem utilizada em conjunto com uma aula teórica, pois ela é de fácil manejo e de fácil compreensão, o que torna uma aula muito mais interessante e divertida. A velocidade do Método II é mais baixa pois os cálculos foram feitos com valores experimentais e já o Método I mostrou a velocidade máxima, pois não consideramos perdas neste método, como o atrito, a turbulência, a elasticidade dos capilares, formação de bolhas etc. Ao final podemos dizer que o objetivo de construir uma Fonte de Heron com materiais baratos e de fácil acesso foi bem sucedida, além de termos mostrado que seu funcionamento é de fácil manutenção e de grande ajuda tanto para os alunos no aprendizado da matéria quanto ao professor no auxilio da aula.

7 REFERÊNCIAS (* novas referências)

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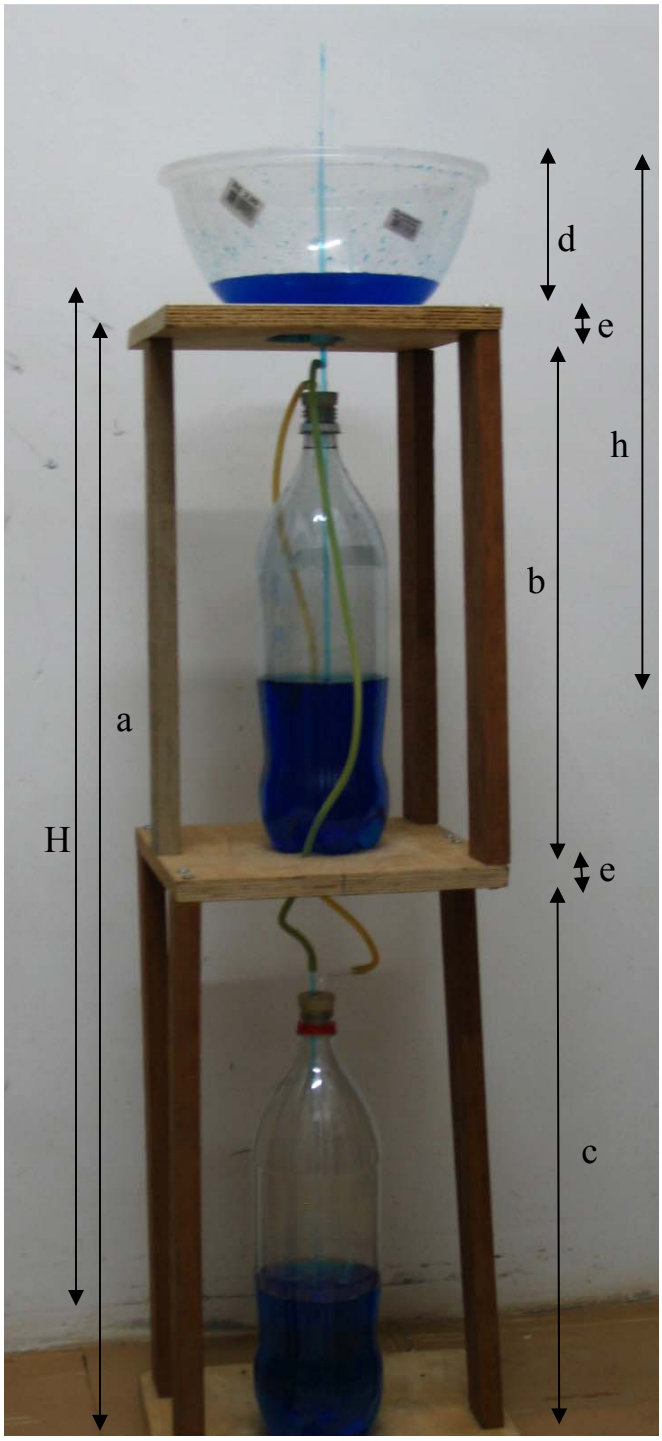
8 ANEXOS



a = 90,6cm
b = 39,75cm
c = 47,45cm
d = 14,5cm
e =1,7cm

http://www.feiradeciencias.com.br/sala07/07_25.asp
Esta referência foi de grande base para nosso projeto. Esta explica bem o funcionamento da Fonte como também ensina a montar o aparato com equipamentos de fácil acesso, além de fornecer dicas de como construir a fonte com uma boa qualidade. Tem uma boa e fácil didática para que possa ser desenvolvido o experimento com grande chance de êxito. Também fornece variações da montagem para uma Fonte de Heron.

Introdução

Com tal montagem você conseguirá facilmente um jato de água de 50 cm de altura, de modo continuo, por mais de 20 minutos, usando apenas como energia inicial, o trabalho de colocar uma garrafa cheia de água numa plataforma elevada. A fonte de Heron (e suas variantes) é o que apresentaremos nesse trabalho.

Material

a) 3 placas quadradas, de madeira (A, B e C), com espessura de 0,5 cm e lados de 15 cm;

b) 2 sarrafos (D e E) de 1 cm de espessura, 5 cm de largura e 150 cm de comprimento.

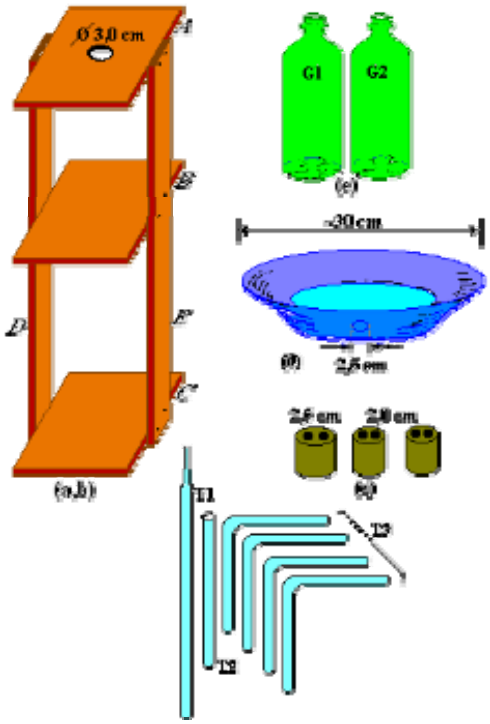
Veja em (a,b), das ilustrações, a montagem dessas peças, formando a "prateleira" de 3 patamares A, B e C. A placa A apresenta um orifício central de 3 cm de diâmetro.

(c) 2 garrafas de refrigerante (G1 e G2) tipo "Big", em plástico, com capacidades de 2 litros. Garrafões de 3l ou 5l também servem; o inconveniente é que, em geral, têm boca por demais estreitas.

(d) 1 bacia de plástico (BP), redonda, com diâmetro de cerca de 30 cm, com um furo central em seu fundo, com diâmetro de 2,5 cm. Forma de "pizza" ou de bolo também servem.

(e) 3 rolhas de borracha ou cortiça dura, com dois furos cada: uma (a grande - R1) que se adapte ao furo da bacia e ao orifício da plataforma A e as outras duas (R2 e R3) que sirvam para as bocas das garrafas plásticas ou garrafões.

Ilustração do material



Todos os furos nas rolhas devem permitir a passagem (apertada) de tubos de vidro de 6 ou 7 mm de diâmetro externo.

(f) 1 tubo de vidro (6 mm) com uma das extremidades afunilada e cerca de 15 cm de comprimento (T1) ; 1 tubo de vidro reto com cerca de 8 cm de comprimento (T2) ; 4 tubos de conexão em L (cotovelos em 90 graus), com pernas de 5 cm de comprimento (T3). Os tubos de vidro, comuns em laboratórios de química, com alguma perícia para trabalha-los sobre o bico de Bunsen, resolvem essa parte do material necessário.

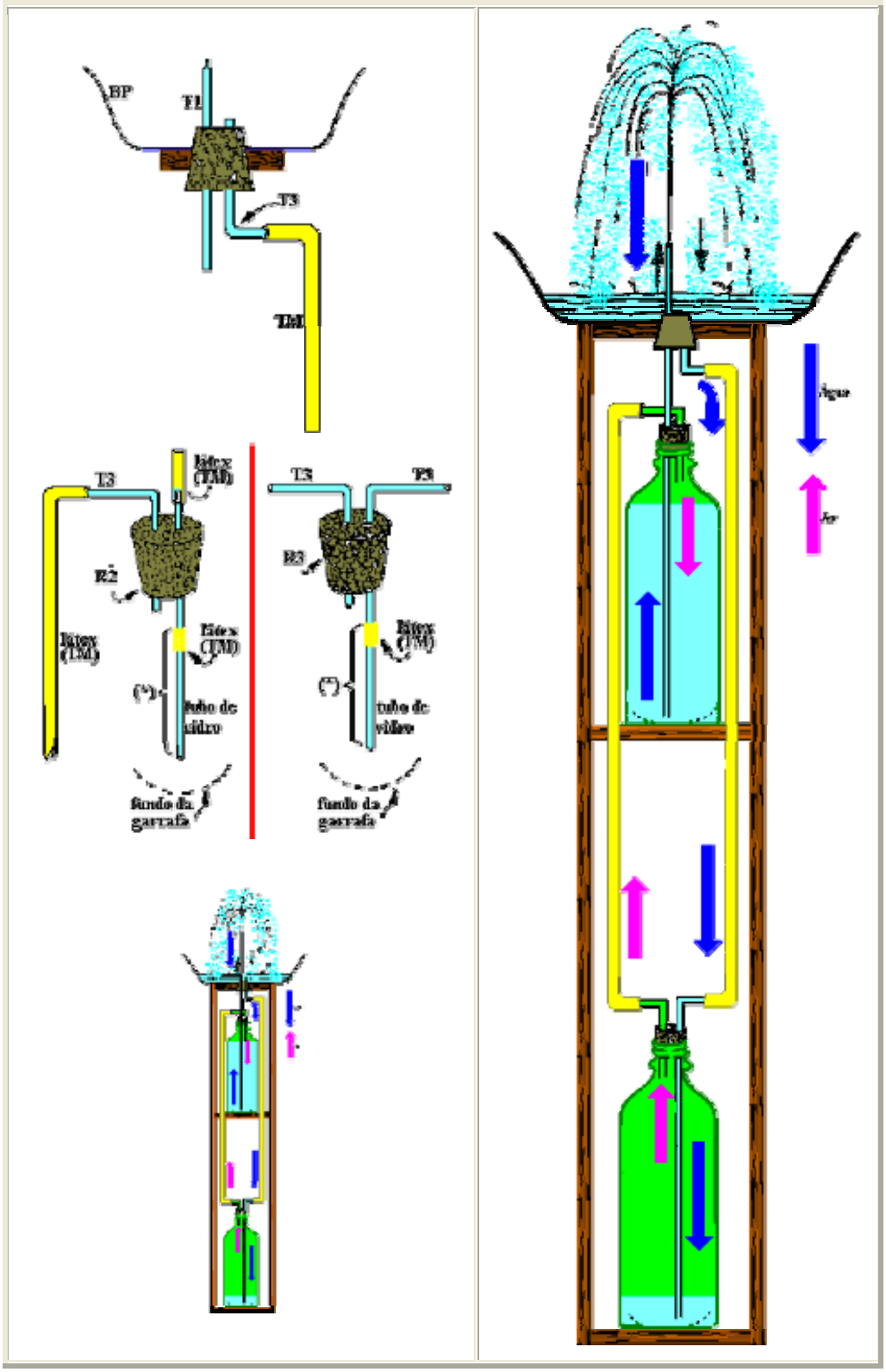
(g) 2,5 metros de "tripa de mico" (TM) (látex) ou tubo plástico flexível (mangueirinha) de diâmetro interno igual ou ligeiramente menor que o diâmetro externo dos tubos de vidro.

Montagem

1) Na rolha grande (R1) passe os tubos (T1) e (T3); numa das pequenas (R2) passe os tubos (T2) e (T3) e na última (R3) passe os dois tubos restantes (T3).

2) Cole o fundo da bacia na plataforma A, com os furos coincidindo. Após secagem, pela face inferior de A, introduza a rolha grande (R1) no furo, até parte da rolha sobressair no fundo da bacia. No ramo horizontal do cotovelo (T3) adapte um tubo de plástico transparente ou "tripla de mico" (TM).

3) Na rolha que vedará a garrafa superior (R2) (já com seus tubinhos de vidro), coloque pequenos pedaços de tubo flexível (látex ou tripa) nas extremidades do tubo reto. Na conexão plástica desse tubo reto, adapte um tubo de vidro que chegue até o fundo da garrafa. Você pode substituir esse tubo de vidro por um tubo plástico flexível que chegue até o fundo da garrafa. Faça o mesmo com um dos tubos de vidro da garrafa inferior.



Nota: Com certa perícia e boa cola, as rolhas das garrafas podem ser substituídas pelas próprias tampas plásticas dessas garrafas. Para boa rigidez do sistema recomenda-se usar "durepoxi". Vide modo de usar na própria embalagem.

4) Fase final: Coloque água até o gargalo na garrafa superior e adapte sua rolha bem firme (não pode vazar ar). Coloque essa garrafa na plataforma B e encaixe o tubinho de látex (TM) na extremidade inferior do tubo de vidro afunilado da bacia.

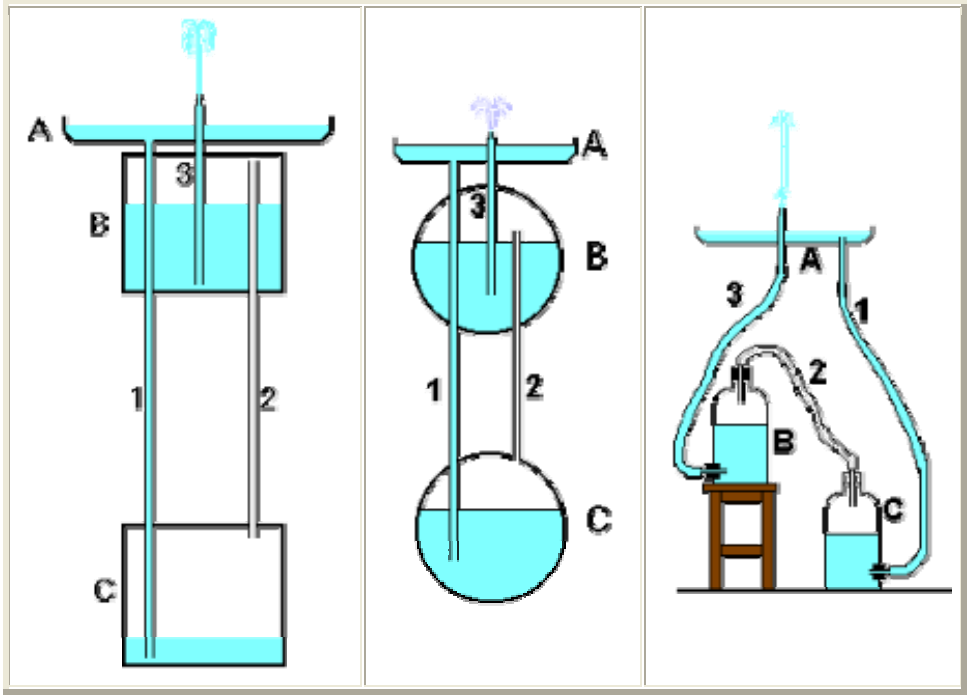
Com a tripa de mico (ou mangueirinha), ligue o cotovelo da garrafa superior (T3) com o cotovelo (T3, da esquerda) da garrafa inferior. Essa é a hora certa de você ajustar o comprimento correto da "mangueirinha", antes de corta-la definitivamente.
Adapte a mangueirinha que vem da bacia ao cotovelo (T3, da direita) da garrafa inferior. Esse é o cotovelo que tem a tal emenda que vai até o fundo da garrafa.
5) Com a garrafa de cima cheia de água, para funcionar, basta colocar um pouco de água na bacia, até cobrir a boca do tubo (T3) que deve sobressai ligeiramente da rolha.
Dai para a frente a "coisa" funciona por "conta própria".

Funcionamento

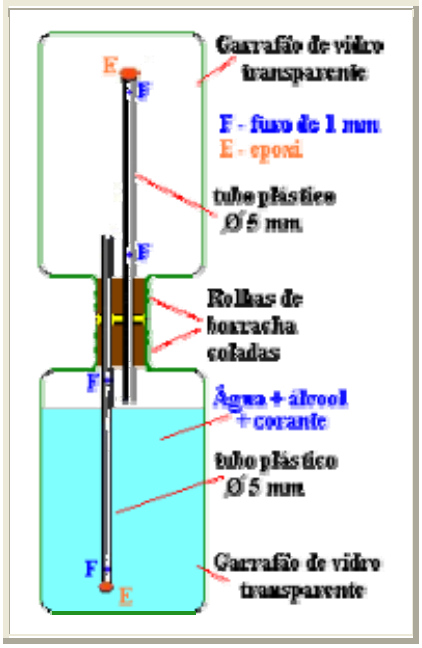
A energia inicial para o funcionamento do sistema foi dada quando você colocou a garrafa na prateleira de cima. Com isso ela adquire energia potencial em relação à garrafa de baixo. Essa energia potencial inicial mais a pressão atmosférica manterão o funcionamento até que se esgote a água da garrafa superior.
A água colocada na bacia, penetra na mangueira e vai até a garrafa inferior, comprimindo e forçando a saída de ar dessa garrafa, pela outra mangueirinha. O ar que dela sai, entra na garrafa superior, via (TM), aumentando a pressão nos pontos do interior dessa garrafa. Isso força a água a subir pelo tubo central e a jorrar pelo tubo afunilado.
A água que jorra, cai na bacia (por isso a bacia deve ser suficientemente larga para recolher essa água), entra na mangueira e vai para a garrafa inferior, forçando mais saída de ar dessa.
E o processo continua até que toda a água da garrafa superior passa para a inferior, via bacia.
Depois, é só afrouxar as rolhas e trocar as garrafas de posição --- Cheia em cima, vazia em baixo.
Vale a pena ver isso funcionar!

Variações de montagem

As montagens I, II e III são equivalentes. As partes básicas são: A - plataforma; B - reservatório superior; C - reservatório inferior; 1, 2 e 3 - tubos de vidro (ou plástico) e Líquido = água + corante

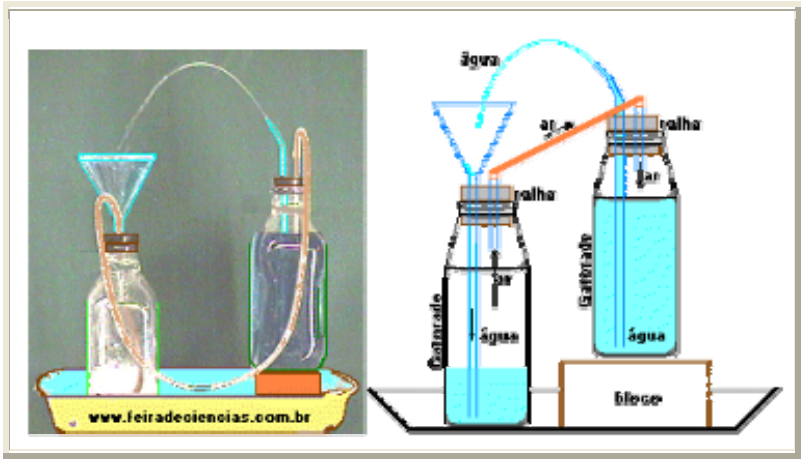


As montagens acima foram feitas em vidro (frascos para aquário e globos). Os suportes de madeira não são mostrados.
Em III usou-se de garrafões de laboratório de química com abertura próxima ao fundo (frascos para decantação). Isso também pode ser feito com garrafas plásticas de 2 litros, com furos próximos à suas bases.

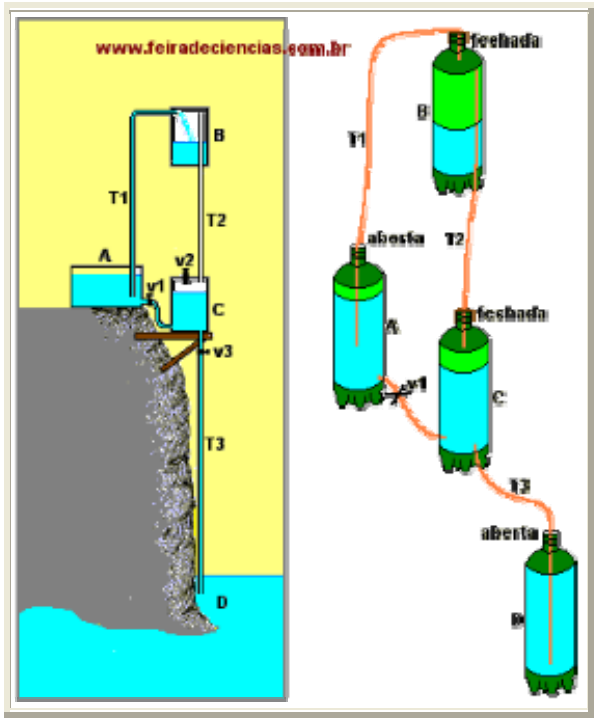


Em IV temos uma montagem estanque (nada se comunica com a atmosfera). Os tubos de plástico devem ter uma de suas extremidades (E) vedadas com massa epoxi (durepoxi). Em cada tubo, nas posições indicadas, devem ser feitos furos (F) de diâmetro 1 mm. O líquido é uma mistura de água e álcool (20 ml de álcool para cada litro de água) com algum corante orgânico. Para reiniciar o funcionamento basta girar todo o sistema.

Versão com garrafas de Gatorade



A técnica de funcionamento da fonte de Heron pode ser útil para elevar água desde um reservatório A até outro reservatório B, utilizando um reservatório intermediário C e um local para vazão de água D, em nível mais baixo. Analise a ilustração da esquerda na figura abaixo e descreva o funcionamento, --- percebeu que o tubo T3 deve ser algo mais comprido que o tubo T1? A ilustração à direita é uma sugestão prática para exibir o projeto em Feira de Ciências (não esqueça, T3 > T1).


www.feiradeciencias.com.br
B
T1
T2
A
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v1
C
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D
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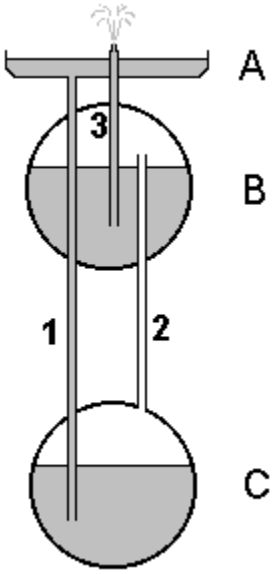
C
T3
aberta
D

http://www.searadaciencia.ufc.br/sugestoes/fisica/flu5.htm
Nesta outra referência há uma simples descrição do funcionamento da fonte, como também fornece uma fácil visualização de como ocorre o transporte de líquido entre os frascos. Também fornece dicas de como construir uma fonte com maior eficiência.

Objetivo
Um interessante dispositivo que ilustra alguns conceitos da Hidrostática.



Descrição

Essa é uma fonte que parece desafiar a lei da conservação da energia.
Consta de um recipiente aberto (A) e dois fechados (B e C) ligados por três tubos 1, 2 e 3, como mostra a figura. A água cai de A para C pelo tubo 1 e empurra o **ar** pelo tubo 2 para o recipiente B. A água em B, pressionada pelo ar que vem de C, sobe pelo tubo 3 e jorra com um jato pela ponta do tubo. Quando o recipiente B se esvazia, a fonte pára de funcionar.

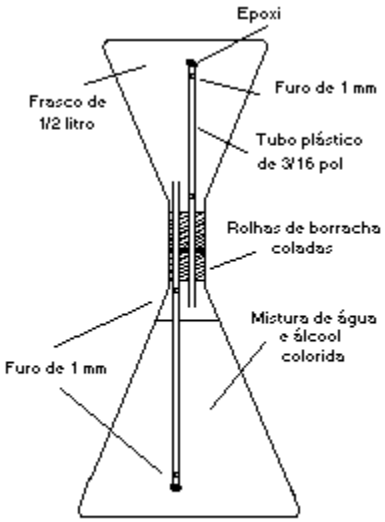
Análise

A explicação para o funcionamento dessa fonte fica clara quando observada ao vivo. Os aumentos de pressão causados pela água que cai no recipiente C e pelo ar que sobe pelo tubo 2, empurram a água pelo tubo 3, fazendo-a jorrar pela ponta fina desse tubo..

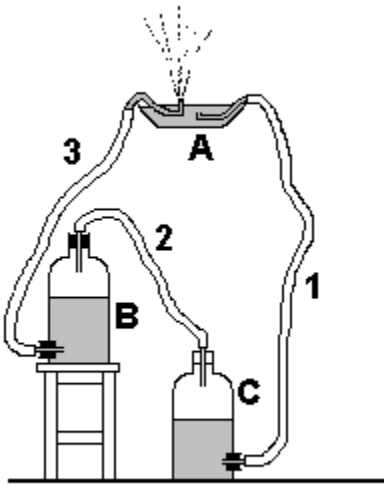
Material

Dois frascos de 1 ou 2 litros. Garrafas plásticas de refrigerante podem servir, embora tenham uma boca estreita.
Rolhas de borracha, cortiça ou qualquer material adequado. Para fazer os furos nas rolhas peça ajuda a um mecânico habilidoso.
Tubos plásticos rígidos.

Dicas



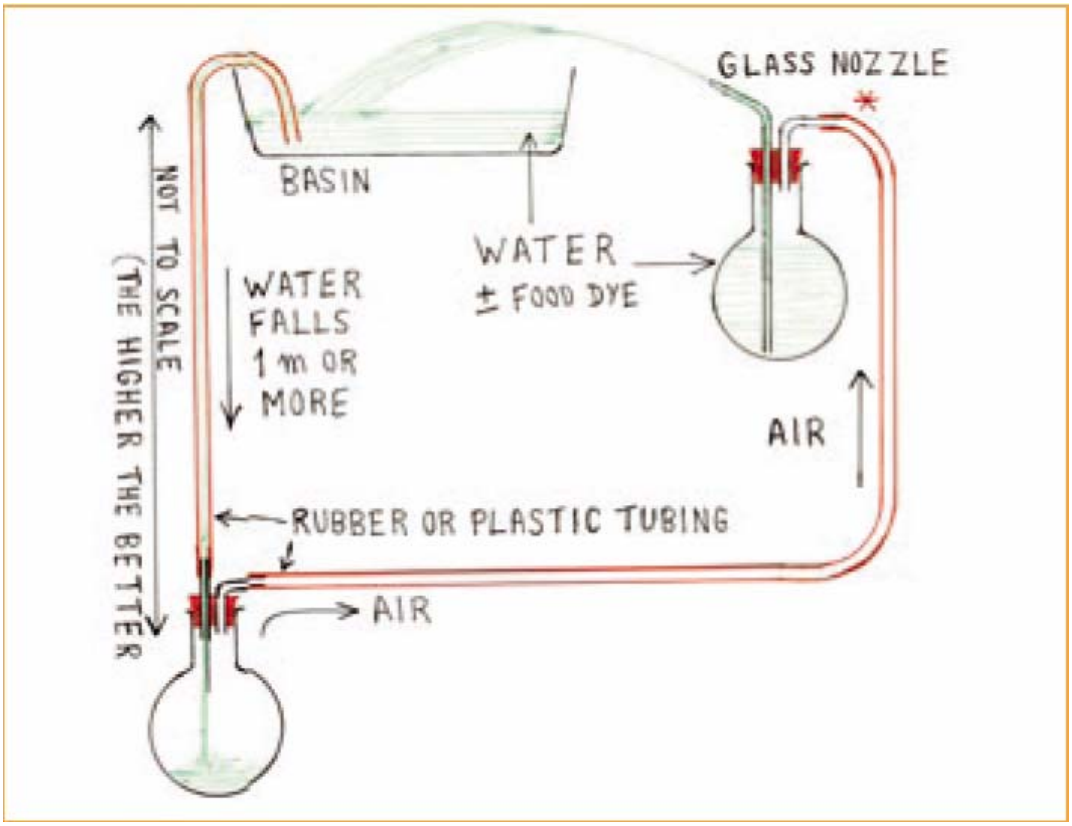
Existem muitas variações do arranjo descrito acima. Pode ser que você ache uma que julgue mais eficiente. A figura ao lado é uma delas.
Use dois frascos grandes, rolhas com dois furos cada e dois pedaços de tubo plástico rígido. Cole as rolhas uma na outra de modo que os furos coincidam. Prepare os tubos tampando um dos lados com epoxi e fazendo dois furos em cada um. Um dos furos fica próximo da ponta tampada com epoxi e o outro fica em uma posição próxima da rolha (veja a figura). Encha o frasco com uma mistura de álcool e água (20 ml de álcool por litros dágua) e ponha um pouco de colorante na mistura.
Invertendo o conjunto, a água passa pelo tubo baixo para o frasco de baixo, comprimindo o ar. O ar entra no outro tubo, arrasta líquido pelo furo de baixo e carrega esse líquido até o furo de cima formando um jato pulsante que continúa por cerca de 2 minutos ou mais. O processo é repetido invertendo o conjunto.
A outra figura ilustra uma variação mais interessante que você pode montar com garrafas de refrigerante. O princípio é o mesmo mas a montagem é mais simples. Quando toda a água tiver passado da garrafa B para a garrafa C, basta trocar as posições de B e C e a ponta do tubo 3 que a fonte recomeça. Outra vantagem: pode-se mudar a disposição para ver a influência da altura de B sobre o jato da fonte.



http://ireland.iop.org/sos/pos2book/POS2%20booklet.pdf
Esta foi uma fonte que encontramos na web onde foi mostrada numa feira de ciências. Com os desenhos fornecidos abaixo consegue-se compreender o funcionamento da fonte. Nota-se que um simples aparato pode fornecer compreensão a teorias (Principio de Pascal e Bernoulli) ditas em aulas.

'Heron's Fountain' **[Heron is also known as Hero of Alexandria]**

SWEDEN: Per Olaf Nilsson demonstrated a more elaborate version



A small fountain sprays water into a basin. The fountain is supplied by a flask of water **below** it. Water from the basin drains into second flask which is lower down. Ask students how the water has enough energy to spray out of the fountain at the top. We made this simple version using only standard laboratory items. It was also very easy to start by sucking air through the plastic tube at * then it ran for about 10 minutes before the flasks needed to be exchanged. Try increasing the height of the head of falling water. We used:
2 flasks (1 litre or 500 ml, conical or flat bottomed, what the heck?)
2 two-holed rubber bungs to fit the flasks.
2 metre, or so, of plastic or rubber tubing to fit the glass tubing.
1.5 m of 6mm glass tubing, cut into 4 pieces and worked as shown.

http://brunelleschi.imss.fi.it/museum/esim.asp?c=415019
Esta referência conta um pouco da historia de quem foi Heron, pois queríamos saber porque a Fonte de Heron leva esse nome. Alem disso, queríamos saber o que influenciava na época em que viveu e também onde viveu. Queríamos também saber o que fazia pois alem desta fonte Heron contribui com outros trabalhos tanto na área da física como na matemática.

XV.19 Hero's fountain

Inventor: Hero of Alexandria
Maker: unknown
Date: Second half 18th C.
Dimensions: Height 1180 mm, base 580x580 mm
Current inventory: 2153
Materials: Wood, brass, glass

Hardly anything is known about Hero's life. The century in which he lived was identified by dating a lunar eclipse observed by him to March 13, 62 C.E. Mathematician and engineer, taught technical subjects at the famed Museum of Alexandria. A careful reader of Ctesibius and Philo, Hero also made a close study of the works of Euclid and Archimedes, from which he drew fruitful lessons. The author of many treatises, Hero forcefully asserted the need for comprehensive training that combined theory and practice. In his mathematical and geometrical works (*Definitiones*, *Geometria*, *Geodaesia*, *Stereometrica*, *Mensurae*, *Metrica*), Hero proposed brilliant systems to solve measurement problems, illustrated the invention of a method to approximate square roots and cubic roots of numbers that are not perfect squares and cubes, and identified the formula (known as Hero's formula) to determine the area of a triangle from its sides. Thanks to a Latin version of the *Catoptrics*, we know that Hero made another noteworthy contribution to optics by correctly defining the laws of reflection. In his treatise on *Dioptrics*, Hero described the use of a theodolite of his invention; there is also a chapter on astronomy in which he provided the method for computing the distance between two cities—Rome and Alexandria—from the difference between the local hours at which a lunar eclipse was observed.

Hero also wrote treatises on specific disciplines. The *Pneumatics*, now regarded as a work of great significance, opens with a theoretical introduction followed by the description of many devices powered by water pressure, steam, and compressed air. The author displays his skills as inventor, describing apparatuses such as the Aeolus cell and what came to be known as Hero's fountain. The Aeolus cell or *Aeolus sphere* demonstrates how thermal energy can be converted into mechanical energy by harnessing the pressure generated by heating water inside a metal sphere.

Hero also left a treatise *On the construction of war machines*. His work *On automata* describes small automated stages that could be set in autonomous rectilinear or circular motion for the entire duration of a theatre performance.

Hero's masterpiece, however, is the treatise on *Mechanics*, which has come down to us only in Arabic translation. In this work, the Alexandrian scientist offered the first definitive framework for theoretical and practical mechanics by stating that all five basic machines—the lever, the winch, the pulley, the screw, and the wedge—operated on the basis of the lever principle. There are also surviving fragments of Hero's writings on *Water clocks*, and *Commentaries* on Euclid's Elements.

This type of fountain, described by Hero of Alexandria, was a fairly popular apparatus in physics collections up to the early twentieth century. A carved and decorated wooden tripod supports two stacked glass globes fitted with brass collars. The upper globe carries an engraved glass cup. A tube connected to a small hole in the cup runs through the upper globe and into the lower. A second tube connects the two globes. A third, shorter tube runs from the middle of the upper globe to the center of the cup, ending in a nozzle. To operate the apparatus, one must fill the upper globe with water. The fountain is primed by pouring water in the cup. The water flows into the lower globe, expelling air into the upper globe, where it is compressed. As a result, the water in the upper globe is driven by the air pressure up the shortest tube and spurts from the nozzle, falling back into the cup. The fountain continues to function until the lower globe is full and the upper empty. Hero's fountains—made in different designs and of various dimensions and materials—or similar devices such as intermittent fountains were sometimes used as eye-catching table centerpieces for dispensing wine or colored beverages. The construction features of this specimen are typical of the French machines described by Jean-Antoine Nollet. Provenance: Lorraine collections.

http://tritium.fis.unb.br/exper/prolego/index.html
Nesta referência fornece uma explicação do funcionamento da fonte, mas é de difícil visualização desta, já que o aparato não é construído de forma simples. Mas esta referência é importante pois mostra que esta fonte também já foi construída por alunos e não apenas para ser de exposição para feiras de ciências.

Fonte de Heron

A Fonte de Heron foi criada há aproximadamente 2.200 anos. A fonte é formada por duas câmaras e a pia, onde a água jorra. Um tubo (A), liga a pia a câmara inferior; outro tubo (B) liga as duas câmaras, e um terceiro (C) tubo, finalmente, liga a câmara superior à pia, fechando o ciclo. Enche-se o primeiro compartimento de água até a borda do tubo B. Depois coloca-se água na pia da fonte, que por sua vez desce pelo tubo A até o segundo compartimento. Este que estava todo preenchido por ar. A água chega e empurra o ar através do tubo B para o primeiro compartimento. Este estava cheio de ar e água, previamente colocada. O ar que sobe do segundo compartimento empurra a água para cima por um outro tubo, a água entao é jorrada. O ar é empurrado para que a pressão no segundo compartimento não aumente em relação a pressão atmosférica, a mesma explicação pode ser dada para o primeiro compartimento, onde a água é pressionada.

http://chemmovies.unl.edu/chemistry/beckerdemos/BD013.html
Esta referência também foi de grande valia pois contem filmes que nos mostram a forma com que o liquido é jorrado pela fonte. Como no nosso experimento os filmes mostram que o líquido sae algumas vezes de modo contínuo outras ele sae em turbulência (modo meio oscilatório). Nesta parte anexa existem alguns filmes da fonte, então recomenda-se entrar no site acima para visualizar os filme que estão indicados abaixo. Não consegui fazer com que eles sejam acessíveis por este anexo, por isso aconselho a entrar no site. Esta referência foi extraída de uma universidade, e além disso mostra que esta foi usada em laboratório de física para que os alunos aprendessem os princípios utilizados no seu funcionamento. O professor mostrava o experimento e depois os alunos tinham que responder a questionários mostrando que tinham aprendido a teoria na sala e confirmando aquilo aprendido no laboratório. Esta referência também mostra os princípios claramente usados no funcionamento da fonte, sendo de grande interesse na parte didática.

EXPT 013 -- HERO'S FOUNTAIN
Description

With no electrical cord or batteries or obvious energy input of any kind, a fountain spouts and sprays gracefully for quite a while. At first, the fountain looks like a perpetual motion machine. With time, however, and careful observation, a transfer of water can be noticed from a higher reservoir to a lower one, revealing the fountain to be nothing more than an elaborate siphon.

Chemical Concepts

1. Energy in conserved.
2. Potential energy may be converted into kinetic energy.
3. The activation energy of a process is the extra energy required to change from one stable state to another. Extra energy is frequently required to initiate a change even when the change is exothermic.
4. The energy of reaction is the difference in potential energy stored in chemical bonds before and after reaction.

Safety

- Hot glass and hot objects can cause burns. Hot glass and cold glass look exactly alike. Hold a finger near a previously-heated object for several seconds before touching it to detect heat. Do not grasp hot objects.
- Use extreme care and plenty of glycerin when inserting tubing in rubber stoppers. Always hold the stopper from the side.

Procedure

Set up the apparatus at one side of the lecture table where it can continue without interfering with other activities.

1. Fill the left hand bottle with water and place it about 20 cm higher than the right hand bottle, insert stoppers securely, then pour about 500 mL of water in the funnel. Carefully, mark the water level in each bottle.

   !!!Click here to See Movie.
   !!!Click here to See Picture. An enlarged scrolling view of apparatus.
   If there is any problem, set the lower bottle on the floor until the fountain starts up. While it is tempting to leave the bottle on the floor spouting a tall column of water, the funnel may go dry because so much water is spattered about the laboratory that the tubes drain faster than the funnel is replenished.

2. If the fountain is irregular, flick the tip with your finger. If the tip is aligned and clean, a fine vertical stream disperses into many smaller streams above the tip.

   !!!Click here to See Movie.

3. Move the lower bottle to different levels to illustrate the change of potential energy (the water levels) to kinetic energy (the velocity of the water on exit). The kinetic energy changes back to potential energy as demonstrated by the height of the fountain. Query students about the energy changes at each point.

   !!!Click here to See Picture.

4. Optional: From a distance, charge an inflated balloon by rubbing it against your hair. Hold it toward the fountain. On a dry day, the static charge affects the fountain from several feet away.

   !!!Click here to See Movie.

5. After the fountain has run a while, point out to the students the water levels in the two bottles. It takes a long time to show much difference. To accelerate the change you may remove the narrow glass tip. The fountain effect is lost but you can perceive a change in the water levels within 3 minutes.

   !!!Click here to See Movie. In order to display the siphon action, the tip is removed, and the time-lapse movie is accelerated 30 times.

Questions

1. Label the point in the apparatus where water has the lowest potential energy in the system.
2. Label the point in the apparatus where water has the highest potential energy.
3. Label the point in the apparatus where the water has the minimum potential energy required to transport it through the funnel to the lower bottle.
4. Label the point in the apparatus where water has the highest kinetic energy.

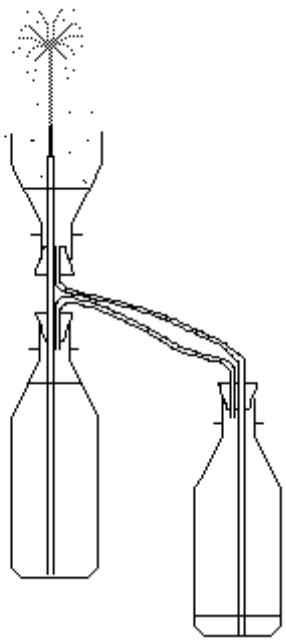
5. For chemicals to react, stable molecules must acquire enough potential energy to break the old bonds and form new ones. The potential energy required in this state is the activation energy. Label the point in the apparatus that is analogous to the potential energy hump called the activation energy.

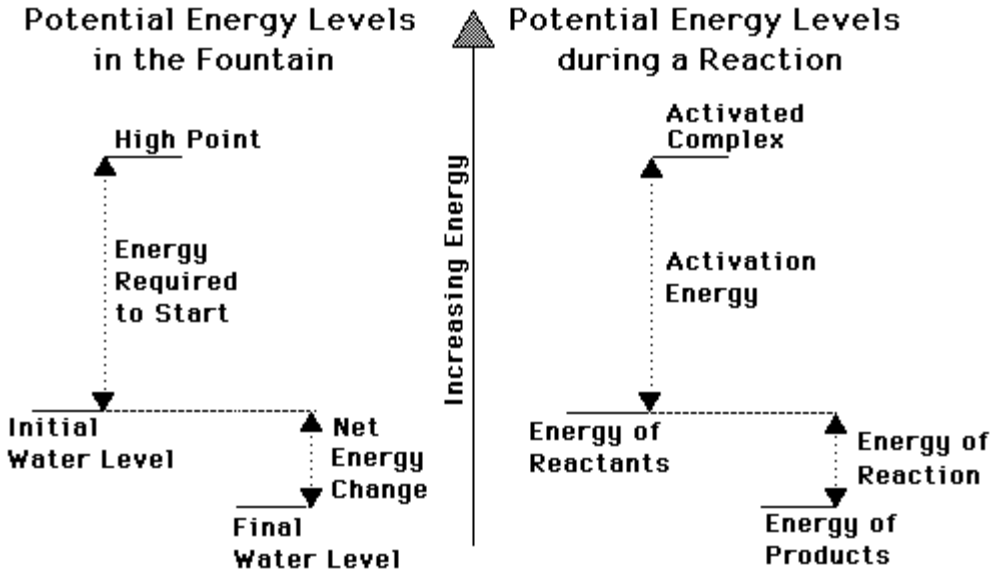
Handout

Name _____ Class _____

Teacher _____

BeckerDemos 013 Hero's Fountain





Handout Makeup

Name _____ Class _____

Teacher _____

BeckerDemos 013 Hero's Fountain

Watch the movies.

Label the diagram as requested in the Questions.

Curriculum-

- This activity fits into discussions of energy, particularly potential energy. For beginning students, you may wish to limit discussion to energy changes.
- Analogies between the fountain and those abstract activation energy level diagrams in kinetics chapters help students picture the levels. Couple this activity with some exothermic reaction that requires activation energy to clearly illustrate the significance of the activation energy. The burning of a wax candle is an excellent comparison.

Activity-

Demonstration - Student or Teacher

This demonstration works well if you set it up early in the period over at the side with minimal explanation. Later in the period when students can see the difference in the levels explain the energy changes. Energy level diagrams and a diagram of the apparatus are included in the Figures if you wish to have students label these diagrams when you return to the demonstration.

Safety-

- Hot glass and hot objects can cause burns. Hot glass and cold glass look exactly alike. Hold a finger near a previously heated object for several seconds before touching it to detect heat. Do not grasp hot objects.
- Do not allow students to insert glass tubing into rubber stoppers. They may cut themselves severely.
- USE PLENTY OF GLYCERIN WHEN INSERTING THE TUBING THROUGH THE STOPPERS. Place the stopper on the desk and push the tubing into it. Hold the stopper from the side to finish inserting the tubing.

Time-

Teacher Preparation: 5 minutes (Construction 15 minutes one time.)

Class Time: 15 minutes (Start early in the period to allow time in order to come back and check the level after 20 minutes.)

Materials-

- 3 2-L soda bottles
- 3 2-holed stoppers (#3) to fit bottles
- 80 cm glass tubing (6-mm OD) or 80 cm rigid plastic aquarium tubing -- 5-mm OD and 12 cm glass tubing
- water

See Lab Hints for construction information.

Optional:

- a balloon

Disposal-

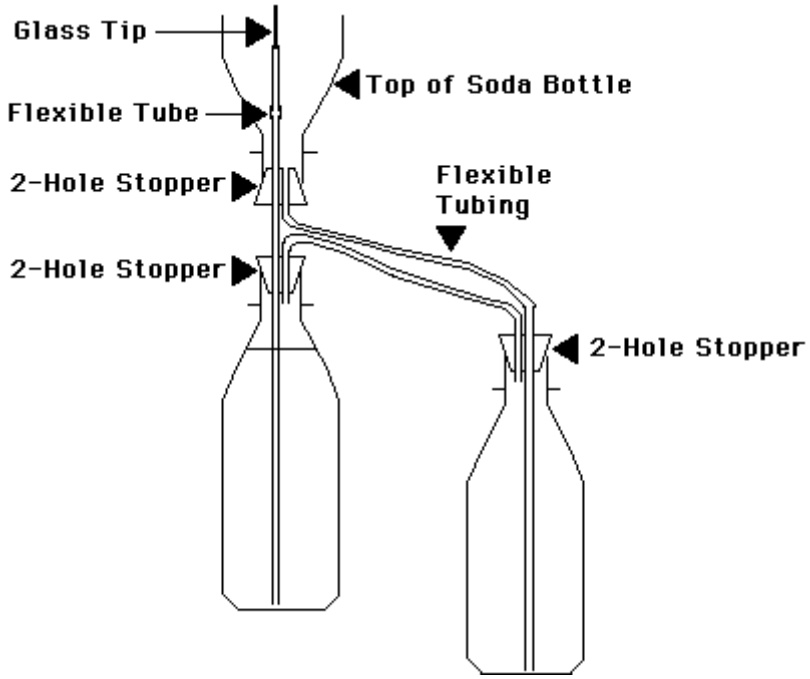
Save apparatus for future demonstrations.

Lab Hints-

Do not add coloring to the water. During the demonstration, your surroundings and clothes are spattered with a fine mist of the water (with the food coloring if included). Colorless water is more visible in the laboratory than on a two dimensional video so the coloring is not an asset.

Construction (time - 15 minutes):

1. Score and break a glass tube into six pieces -- 38 cm, 32 cm, 12 cm, 4 cm, 4 cm and 4 cm. Fire polish all ends and allow to cool.
2. Heat and stretch the 12 cm length to make two finely tapered pieces. Use glass for this one.
3. Cut two lengths of flexible aquarium tubing each about 80 cm long. Cut off the top third of a 2-L soda bottle, and assemble the fountain as illustrated below



USE PLENTY OF GLYCERIN WHEN INSERTING THE TUBING THROUGH THE STOPPERS. Then rinse the glycerin off when you're done. Hold stoppers by the sides.

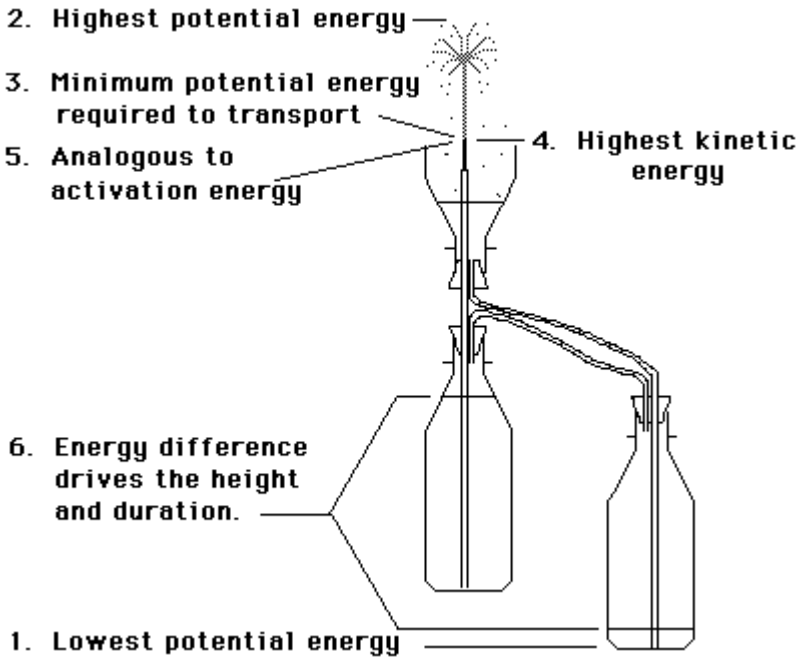
Observations-

- Initially the pressure in each bottle, A (upper) and B (lower), is equivalent to atmospheric pressure. As water is poured into the fountain bowl on top, it drains down through hose #1 into the lower bottle (B) and creates additional (hydrostatic) pressure there. If, for example, the water level in the bowl is 100 cm higher than the water level in bottle B, then the air pressure inside B must increase to 1 atm + 100 cm water. Since the air pockets in A and B are connected by hose #2, the pressure in bottle A must also rise to 1 atm + 100 cm. In other words, since the pressure outside the fountain is only 1 atm, the pressure in bottle A should be able to support a column of water 100 cm tall. Since the tapered nozzle is only about 20 cm above the water level in bottle A, the water is easily pushed up through it -- with enough pressure left over to spray droplets upward, creating the fountain effect.
- If bottle B is lowered even further, then the hydrostatic pressure increases inside B, and consequently inside A as well, causing the fountain to spray even higher. Conversely, if bottle B is raised relative to the bowl, the hydrostatic pressure decreases, and the fountain spray diminishes. If we use "x" to denote the vertical distance between the water level in the bowl and the water level in bottle B, and we use "y" to denote the vertical distance from the water level in A up to the top of the tapered fountain head, then the fountain always sprays upward with a force proportional to x - y. As soon as y equals or exceeds x, the fountain stops.
- Note that the water draining down from the bowl into bottle B is being replaced by a more or less equal volume of water spraying up from the fountain into the bowl. Thus, once the fountain is started, it should run continuously without any additional priming. At first glance this may appear to be some kind of perpetual

motion machine. But, since water is draining downward through hose #1 and only air is flowing back upward to replace it through hose #2, the fountain does not flow perpetually, but only until the water in bottle A has drained out completely or, if the bottles are pretty much on the same level, until y = x, as discussed above.

- Another way to visualize the fountain is in terms of potential and kinetic energy: The water is at its lowest potential energy in the lower bottle. The water in the upper bottle does not begin flowing until the fountain is "activated" by adding additional potential energy to the system by pouring water into the funnel. Once the funnel and tubing is full, the potential energy between the upper and lower water levels in the full bottles determine the length and height of the demonstration. The gas pushed out of the bottom flask by water in turn pushes water out of the upper flask changing potential energy into the kinetic energy of the water as they exit the glass tip. At the tip the kinetic energy of the water is largest. The potential energy of the water is largest at the highest point in the stream of the fountain of water. All of the water, which has enough energy to emerge from the glass tip, can flow into the lower bottle.
- The potential energy levels may be used to illustrate the potential energy diagrams frequently used in kinetic explanations. The energy difference between the water levels in the bottles is analogous to the heat of reaction (the difference in chemical potential energy between the reactants and products). The potential energy of the water at the glass tip is analogous to the activation energy. Both are potential energy humps that must be overcome even when energy is stored. The energy is added to start the system, but the system sustains itself with the difference in potential energy of the initial and final energy states. In the end, no water is at the glass tip and no molecular fragments are at the activation energy.
- The optional charged-balloon variation illustrates a very different phenomenon: how an electrostatic field can induce a polarity in another object. The electrically charged balloon attracts opposite charges in the water droplets and repels like charges. Even a slight migration of these charges can establish an induced polarity in each individual water droplet. Since they have been polarized, the droplets tend to coalesce into larger droplets and ruin the spray effect of the fountain. What is most remarkable is that this effect can be observed even when the charged balloon is held several feet away.

Answers-



Key Words 1-

kinetics, activation energy, potential energy, kinetic energy, electrical energy, thermochemistry, energy of reaction

http://physics.kenyon.edu/EarlyApparatus/Fluids/Heros_Fountain/Heros_Fountain.html
Esta referência mostra diferentes formas da fonte e também que esta pode ser comprada. Também explica um pouco o funcionamento da fonte, mas não de forma tão detalhada quanto as outras referências.

Hero's Fountain

Hero's Fountain is a very splashy and attention catching demonstration.

This example of Hero's Fountain is at the collection of the Smithsonian Institution and was probably made by Ritchie ($15.00 in the 1860 catalogue). An important attachment is the drain plug at the bottom to remove the water when the bottom reservoir eventually fills up.

The fountain is primed for use by filling the top and bottom reservoirs half full of water. Water is also poured into the pan at the top until the tube running from the pan to the bottom reservoir is full of water. The fountain then commences to play, and runs until all of the water in the top pan has run down into the bottom reservoir. The first time that the fountain is demonstrated it has all the appearances of a perpetual motion machine; it takes a sharp-eyed student to see that the height of the jet of water of constantly decreasing.

The operation depends on the fact that the weight of the water in the pan and in the pipe from the pan to the lower reservoir compresses the air in this reservoir. The other pipe connects the two reservoirs, and makes the pressure in the upper reservoir essentially the same as the lower reservoir. The extra pressure on the surface of the water in the upper reservoir forces the water up the slender tube leading from it to the nozzle, producing the fountain. It is easy to show that if this tube were long enough, the water would rise in

This demonstration is the collection of Middlebury College. It was made by E.S. Ritchie of Boston and cost $8.00 in the 1860 catalogue.

it until its height above the surface of the water in the pan is just equal to the distance between the water levels in the two reservoirs.

REFERENCE: Thomas B. Greenslade, Jr., "Nineteenth Century Textbook Illustrations, XLI. Hero's Fountain", *Phys. Teach*. 20, 169-70 (1982)

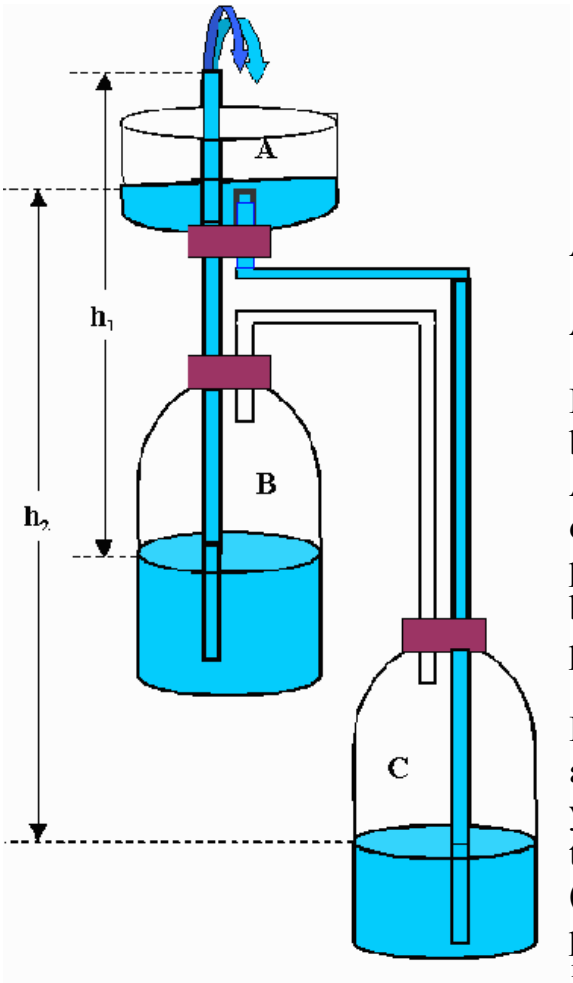
In his 1983 book describing the apparatus in the Garland Collection at Vanderbilt University, Prof. Robert T. Lagemann wrote: "Some of the apparatus of the nineteenth century, as does some of the twentieth century as well, had its origins in antiquity. Pneumatic devices from the Alexandrine School provide a number of examples. If in that day they were often devices meant for the mystification of the layman, and the philosopher too, by the nineteenth century they became understandable in terms of the concepts of the nature of a gas and in reconstructed form could be used to demonstrate their new principles.

Hero's fountain derives its name from its inventor, Hero (or Heron), who lived in Alexandria *circa* 120 B.C.

It is described in his book *Pneumatica* in which Hero describes a number of appliances invented by himself and by a predecessor named Ctesibuis."

This example in the Garland Collection stands 1.05 m high.

http://www.rose-hulman.edu/~moloney/AppComp/2001Entries/e09k/fountain.htm
Esta referência da um bom suporte físico de como ocorre o funcionamento da fonte. Mostra através de expressões matemática os fundamentos físicos da fonte, interpretando bem onde ocorre os princípios de Bernoulli e de Pascal. Através de seu esboço pode-se montar as expressões físicas envolvidas no funcionamento da fonte. Este aparato também foi montado por alunos num Instituto Tecnológico.



Apparatus Title: **Hero's Fountain**

Abstract:

Hero's fountain is dramatic and one of the best demonstration of the topic "Liquids". A new simply constructed, easy-to-make demonstration of the Hero's fountain is presented. Its action is discussed on the basis of Pascal's and Bernoulli's principles.

Equipment required to construct apparatus: To make the magic fountain you need three 2-liter plastic soda bottles, three rubber stoppers #3 with two ¼ " (0.006 m) holes each, two pieces of plastic tubing about 2½' (0.8 m) long and ¼ " glass tube about 3' (1 m) long.

Item Source/Store Part Number Cost

Total cost: less then $10

Description

Figure 1 incorporates a schematic drawing for Hero's fountain. The fountain consists of three parts: a cup A with the fountain tube, and two vessels B and C. The parts are connected as shown in Figure 1. The vessel B is filled with water and the vessel C is empty. Cup A is placed on the vessel B and connected with the vessel C by a hose. Vessel B with the cup can be placed on a table and the other one under the table. When you pour water into the cup A, the water from

the cup flows to the lower vessel C, which contains air, and produces the hydrostatic pressure P2 = rho g h2, additional to the initial atmospheric pressure Patm, of the air in the vessel C. As a result the pressure forces air up to the upper vessel and according to the Pascal's Principle the air transmits this pressure to the water in the upper vessel B. The pressure that air exerts on the water in the vessel B, oppose the atmospheric pressure and the hydrostatic pressure P1 = rho g h1 . Thus, the compressed air in the vessels B and C forces the water to spout out of the fountain's upper tube and drives the fountain.

Hero's fountain is also a good demonstration for Bernoulli's principle. Let us consider again the fluid as an ideal, and determine the speed of the ejected water from the nozzle of the fountain. Use the Bernoulli's principle at the top of the water in the vessel B and the nozzle. The vertical motion of the top of the water in the vessel B is an insignificant. Therefore, the vertical speed of the water at the top in the vessel B is negligible compared with the speed v of the emerging stream of water from the nozzle of the fountain and Bernoulli's equation becomes

$$P_{atm} + \rho g h_1 + \frac{\rho v^2}{2} = P_{atm} + \rho g h_2 . \qquad (1)$$

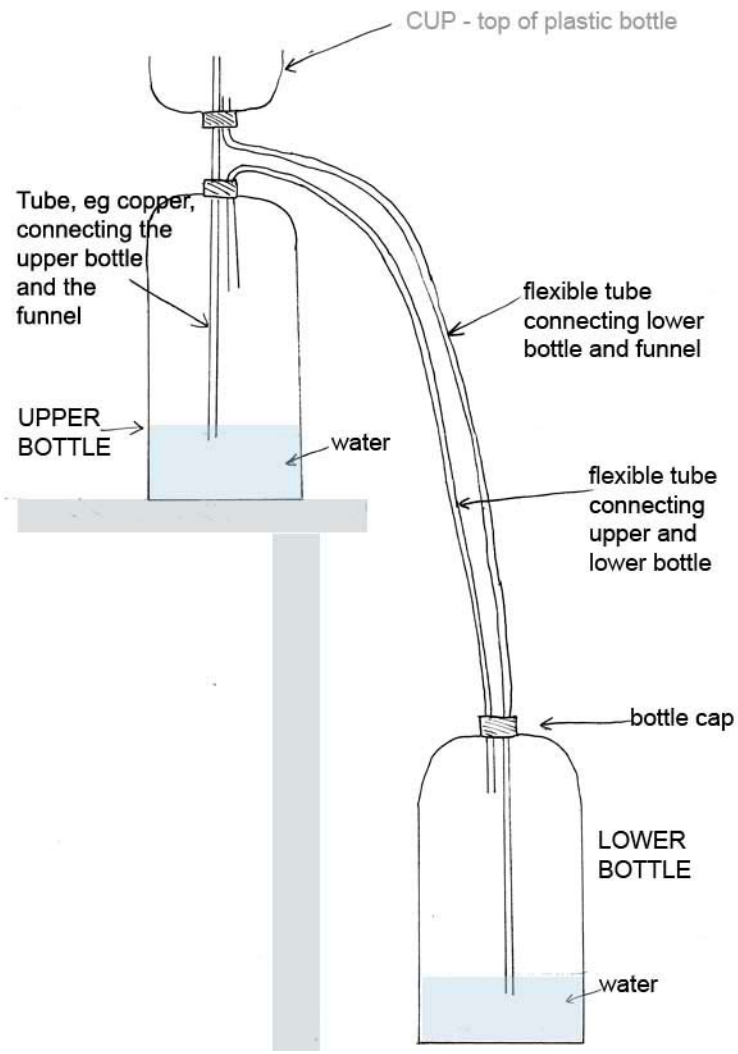
Solving equation (1) for v, we find

$$v = \sqrt{2g(h_2 - h_1)}. \qquad (2)$$

Thus, by moving the vessel ***C*** up and down we can change the pressure of the air on the surface of the water in the vessel ***B*** and as a result, the speed of the water from the nozzle of the fountain will change. When the air pressure increases (vessel ***C*** moves down and as a result the difference of heights $h_2 - h_1$ increases), the speed of the ejected water increases and the water rises higher with respect to the nozzle and vice-versa. In real-life fluids the effects due to the viscosity are significant and the speed of the ejected water will be smaller than that given by equation (2). If we neglect the viscosity of the water the height of the emerging jet above the nozzle would be equal to the difference in heights $h_2 - h_1$.

http://www.easytorecall.com/heros_fountain.htm
Esta referência já mostra alem do funcionamento da fonte o que é uma Fonte de Heron. Esta referência já menciona que para crianças ela pode ensinar a existência do ar e que este pode exercer uma força ocorrendo o fluxo de líquido. Para jovens com mais conhecimentos físicos esta já fornece um entendimento sobre os Princípios de Bernoulli e de Pascal. Esta diz menção a uma referencia já dita anteriormente.

What is Hero's Fountain?
Hero's Fountain is a machine, or apparatus, which produces a jet of water (the fountain) and is powered by compressed air. It was invented by Hero, or Heron, a first century engineer and mathematician from Alexandria.



How to make Hero's Fountain
What you need:
3 2lt pop bottles, clear
copper pipe
clear flexible tubing
sealant
Optional: rubber stoppers

Method:

Look carefully at the diagram. The cup, or top of the apparatus, is made by cutting the top from one from one of the plastic bottles. The other 2 bottles are left intact.

You need to connect the bottles and the cup with tubing. One way of doing this is to make holes in the tops of the plastic bottles and push the tube through the holes. It is *vitally important* that no air can leak through any of the connections, so you must make sure that all connections are air tight. This is where the sealant comes in.

An alternative, and probably less messy, solution is to use rubber stoppers. Unless you buy stoppers with holes already in, you will have to drill holes to allow the tubing to go through. The stoppers you can buy are usually tapered from top to bottom, so measure the diameter of the opening on the bottle to give you an idea of size of stopper you need.

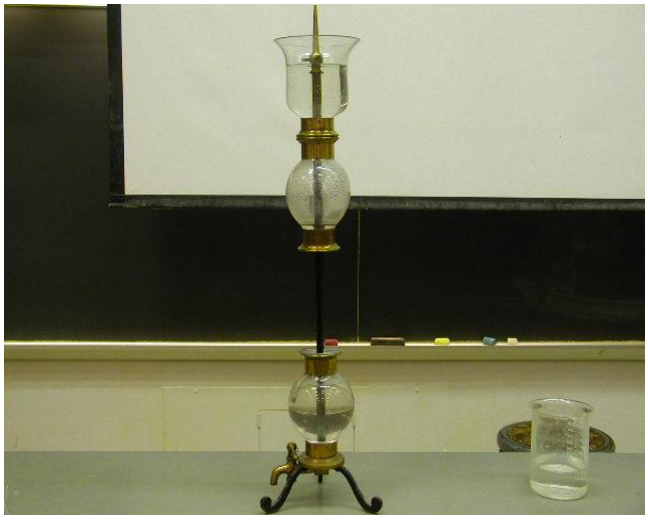
Once you have made all the connections, you need to put water into both the upper and lower bottles. If you have used the bottle caps, you can unscrew them. To get the water

flowing, put water into the cup at the top until it covers the tube leading down to the bottom bottle.

What happens next is that water will flow from the cup down to the lower bottle. This has the effect of increasing air pressure in the lower bottle. In order to equalise the pressure, air is pushed from the lower bottle to the upper bottle. This in turn increase the pressure in the upper bottle. The pressure is equalised here by water flowing up the copper tube to form the fountain. (see picture). The process will continue until the water in the upper bottle has been transferred to the lower bottle.
For younger children, this activity demonstrates that air exists and can exert a pressure enough to cause water to flow out of the tube. Also that pressure can be tranmitted through fluids.
For older children, the experiment illustrates both Bernoulli and Pascal's pricipals.
If you would like a detailed explanation of Hero's Fountain in relation to these principles, there is a pdf document entitled Magic Fountain from Cornell University Library which you can download.
(If you do not have a pdf reader, we recommend Foxit Reader, a free pdf reader which runs on most Windows platforms and which is very fast. Alternatively you can download Adobe Reader, also free, which will run on Windows, Mac, Linux, Palm and mobiles.)

http://groups.physics.umn.edu/demo/fluids/2B6010.html
Nesta tem um filme onde foi verificado o seu funcionamento. Percebemos também que está foi utilizada em uma faculdade em sala de aula para facilitar o compreendimento dos alunos. Isso é de grande ajuda, pois facilita a compreensão dos alunos à teoria. Neste anexo recomenda-se entrar no site, pois tem um filme mostrando a fonte jorrando água. Nota-se que este tem o mesmo problema enfrentado por nossa fonte onde a água não sai de modo continuo da fonte e sim em modo meio oscilante.

Hero's Fountain



Click above to see movie

PIRA Classification: 2B60.10

Description: An antique (1860's) Hero's Fountain is displayed.

Special Instructions: Pour water into the top bowl to start the fountain.

Ideally For: Phys 1101, 1201, 1401

Condition: OK

Setup time: 1 minute

Safety Issues: None

http://faraday.physics.uiowa.edu/heat/2B60.10.htm

Neste anexo recomenda-se entrar no site pois tem um filme demonstrando a fonte que também demonstra alguns problemas que a nossa quando a água é arremessada pra fora. Ela sai de modo oscilante e não contínuo.

Hero's Fountain

CONTENT

Code Number : 2B60.10

Disclaimer:

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The demonstrations contained and referenced herein are listed for the purposes of cataloging and describing physics demonstrations which should be conducted only under the direction of a trained instructional support professional or physicist. These demonstrations are not presented for the purpose of being conducted by persons unconnected to this Facility and/or persons not consulting with or being supervised by the recognized instructional support professional or physicist and his/her staff. The University is responsible only for those demonstrations carried out using its own equipment using established safety and scheduling policies, and bears no responsibility for those choosing to use this source material for their own purposes. All demonstrations described and contained herein are public domain, and can also be found in reference materials in libraries, bookstores, and electronic sources.
Further information regarding legal liability in use of demonstrations and labs will be found on the web site Injuries in School/College Laboratories in USA.
The University of Iowa Disclaimers: U of Iowa Dept. of Physics and Astronomy Disclaimer.

Condition : Good

Principle : Pressure vs. Water Height

Area of Study : Heat and Fluids

Equipment : Hero's Fountain Demo unit, Large Hero's Fountain using two 5 gallon carboys (Glass), Fluorescein, Black lights, Pseudo Hero's Fountain Demo (Pop Bottle Demo).

Procedure : Demo Unit: Fill the top flask with water by sucking on the tapered tube while holding the short tube on the other end of the flask under water. Holding a finger over the tapered tube so that the water does not escape, insert the upper assembly into the lower flask. Fill the cup on the top with water. Remove the finger and water should start to spout due to a compression of air in the lower flask.

The large fountain is exactly the same as the small unit except that the glass tubes are connected with hoses so that a larger separation of the reservoirs can be produced. This in turn gives a greater internal pressure buildup and a greater water stream height. Fluorescein is added to the water for Astronomy demo so that black lights may be used to illuminate this demo for a greater effect. NOTE Take great care with the carboys when filled with water as this makes them super fragile to bumps and scratches.

The pseudo Hero's Fountain demo has made some obvious sacrifices for the sake of reversibility. There are only two reservoirs instead of three. The fountain also is not a continuous stream in this demo but rather an intermittent spurt.

A Low cost Hero's Fountain:
www.rose-hulman.edu/~moloney/AppComp/2001Entries/e09k/fountain.htm

P. P. Ong, "Hero's Fountain: Reversible Model",

TPT, Vol. 30, # 7, Oct. 1992, p. 436.

Virgil E. Stubblefield, "Hero's Fountain: Quick and Squirty", TPT, Vol. 30, # 7, Oct. 1992, p. 437.

Jeff Brooks III, "The Air-Ram Jet Pump- An Improved Hero's Fountain", TPT, Vol. 21, # 5, May 1983, p. 318.

Thomas B. Greenslade, Jr., "Hero's Fountain", TPT, Vol. 20, # 3, Mar. 1982, p. 170.

Fc- 2: Freier and Anderson, A Demonstration Handbook for Physics.

212: "Hero's Fountain," On Gases, Unknown Reference.

Y. Perelman, "Modification of Heron's Fountain," Physics Can be Fun, p. 300 - 303.

Authors: **R.Ya.Kezerashvili**, **A.Sapozhnikov**
Comments: 4 pages, 2 figuresSubj-class: Physics Education; History of Physics
A new simply constructed, easy-to-make demonstration of Hero's fountain is presented. The apparatus doesn't have a vessel above a fountain nozzle or a pump and can be considered as one of the best demonstration of Pascal and Bernoulli's principles. Its action is discussed on the basis of Pascal and Bernoulli's principles. Esta foi a referência com que mais aparenta nosso experimento, também mostra equações que utilizamos na nossa.

Magic Fountain

Roman Ya. Kezerashvili
New York City Technical College, The City University of New York
and
Alexander Sapozhnikov
Brooklyn College, The City University of New York

At last North East Regional Conference of the American Association of Physics Teachers at Princeton University, at the fall meeting of the New England Section of the APS and AAPT at Milton Academy and at the 123rd National Meeting of the American Association of Physics Teachers was presented a simple exited experiment of magic Hero's fountain [1]. This demonstration took and attracted attention of the audience and many questions were raised about it construction and action. We have been asked to white comments about that demonstration. All these motivated us to write this note.

Hero of Alexandria (his name is also spelled Heron) was a Greek mathematician and scientist. He is best known today for an important theorem in plane geometry, also known as Heron's Formula (Hero's Formula), for finding the area of a triangle in terms of its sides. Hero has done his work in Alexandria, Egypt, and has written at least 13 works on mathematics, mechanics, and physics. He developed various mechanical devices, including the aelopile, a rotary steam engine, and water jet produced by mechanically compressed air, -apparatus known as Hero's fountain. He dealt with a number of such engineering devices in his book *Pneumatica* [2]. Hero's fountain, a pneumatic apparatus in which a vertical jet of water is produced and sustained by air pressure, and air forces water above its source.

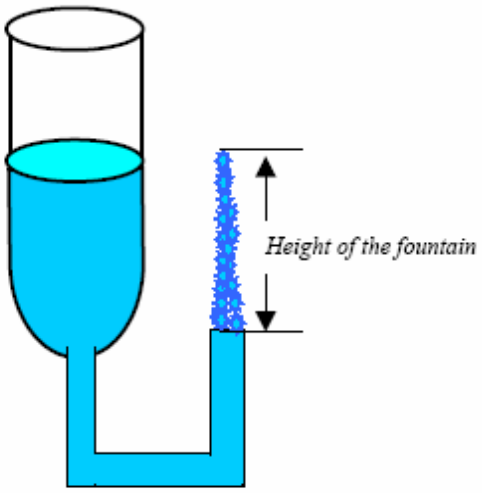

Fig. 1. Gravity-fed Fountain

Well known that the pressure of static fluid is the same at any horizontal level within connected vessels. This principle is underlying of a gravity-fed fountain shown in Fig.1. When the water is projected vertically from the pipe connected to open reservoir it reaches the maximum height that equal to an altitude of the top of water level in the open reservoir. The height of the fountain is a distance between the nozzle of the fountain and horizontal level of the open reservoir. If a fountain is not gravity-fed you need a pump to produce a difference of pressure to supply the fountain.

Today you can find a numerous publications and on the Internet (for example Refs. 3, 4, 5, 6, 7), which are describing operation and different modified constructions of Hero's fountain. The fountain invented by the ancient Greek mechanist doesn't have a vessel above a fountain nozzle or a pump and can be considered as one of the best demonstrations of the properties of liquids, explicitly of Pascal's and Bernoulli's principles, the topic that always discussed in introductory college and university physics. See, for example, Refs. 8 and 9. The construction of our Hero's fountain is rather different than the ancient original one [2] or a traditional demonstration [10] though the principle of the action is the same.

The principle of its action and explanation could be found in the construction of this fountain. Figure 2 incorporates a scheme for the Hero's fountain. The fountain consists of three parts: a cup ***A*** with fountain tubes, and two vessels ***B*** and ***C*** with partially filled by water. The parts are connected with two flexible hoses as shown in Fig.2: the cup ***A*** with lower vessel ***C*** and vessel ***C*** with upper vessel ***B***. The vessel ***B*** with cup can be placed on a table and the other one below the level of the table. The cup ***A*** is maintained on the upper vessel ***B*** and connected with the lower vessel ***C*** by a flexible hose. Initially the pressure in both vessels ***B*** and ***C*** equal to atmospheric pressure. When you fill up the cup ***A*** with water the water from the cup ***A*** flows down to the lower vessel ***C***, which contains air, and produces the additional hydrostatic pressure $P_2 = \rho g h_2$, where □ is the density of water. According the Pascal's principle this additional pressure is transmitted undiminished to all directions and therefore to the air inside of the vessel ***C***. As a result this pressure forces a confined air up from vessel C to the upper vessel ***B***. The forced air from the lower vessel ***C*** squeezes the air in the upper vessel ***B***, and forces the water spout out of the fountain upper tube. At this moment the hydrostatic pressure in the upper vessel ***B*** is equal $P_1 = \rho g h_1$. Thus, the pressure of the water in the fountain is the difference of the hydrostatic pressures in the vessels ***C*** and ***B***. Therefore

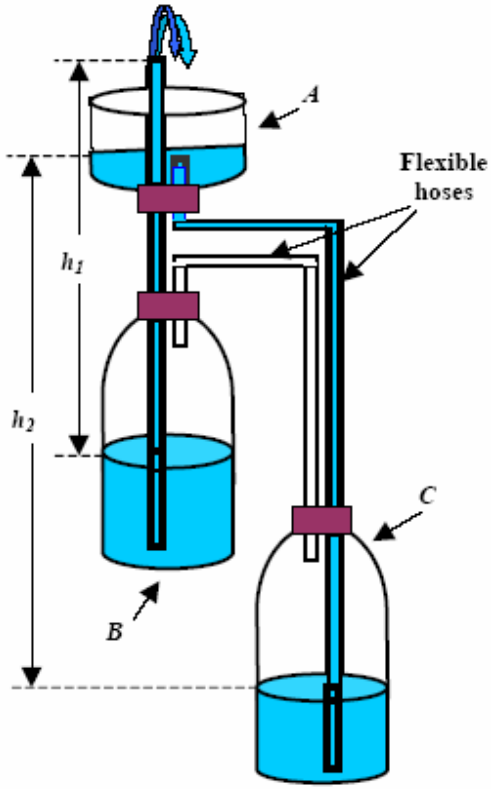

Fig. 2. Schematic presentation for the Hero's Fountain

$$\Delta P = P_2 - P_1 = \rho g h_2 - \rho g h_1 = \rho g (h_2 - h_1). \qquad (1)$$

In other words the pressure ΔP compresses the air in the upper vessel ***B*** and drives the fountain. If we neglect the height of the nozzle of the fountain above the water level in the cup ***A***, difference of heights $h_2 - h_1$ will be equal to the altitude of the top of the water level in the vessel ***A*** measured with respect to the water level in the vessel ***C***. By changing this altitude we can maintain the fountain.

Hero's fountain is also good demonstration for the Bernoulli's Principle. The Bernoulli's Principle is a result of application of the work-energy theorem to a unit volume of a moving fluid. It simply states that the work done on a unit volume of fluid by the surrounding fluid is equal to the sum of the changes in kinetic and potential energies per unit volume that occur during the flow. Let us apply Bernoulli's Principle for the water in reservoir ***A*** and a stream of water from the nozzle. The potential energy of a unit volume of water on the level of the reservoir ***A*** and the nozzle are respectively $\rho g h_2$ and $\rho g h_1$, and kinetic energies are respectively zero and $\frac{\rho v^2}{2}$. Thus we have from Bernoulli's equation

$$P_{atm} + \frac{\rho v^2}{2} + \rho g h_1 = P_{atm} + \rho g h_2 \,, \qquad (2)$$

where P_{atm} is atmospheric pressure. The speed of the stream of water from the nozzle of the fountain tube can be found easily from equations (2) and (1) as

$$v = \sqrt{2g(h_2 - h_1)} = \sqrt{\frac{2\Delta P}{\rho}} \,. \qquad (3)$$

Deriving equation (3) we assuming that a confined air is uncompressible and we neglecting the friction. Of course, the real velocity of water from the nozzle will be less than it is given by equation (3). Consider again the fluid as an ideal by moving the vessel ***C*** up and down we can change the gauge pressure ΔP and as a result the speed of the water from the nozzle will change. When pressure ΔP increases the speed of water increases and the water rises higher with respect to the nozzle creating the fountain effect and vice versus. If bottle ***C*** is lowered even further, then the hydrostatic pressure increases inside ***C***, and consequently inside ***B*** as well, causing the fountain to spray even higher. Conversely, if bottle ***C*** is raised relative to the bottle ***B***, the hydrostatic pressure decreases, and the fountain spray diminishes.

We can visualize the Hero's fountain in terms of potential and kinetic energy. At the beginning the water is at its lowest potential energy in the lower vessel ***C***. The water in the upper vessel ***B*** is stationary. It does not begin flowing until we activated the fountain by adding additional potential energy to the system when we pouring water into the cup ***A***. This is the activation energy of the system. Once the cup ***A*** and tubing is full, the potential energy between the upper and lower water levels in the vessels B and C determines velocity of droplets moving upwards. At the nozzle the kinetic energy of the water is largest. The potential energy of the water is largest at the highest point in the stream of the fountain of water.

To make the magic fountain need three 2-liter plastic soda bottles, three rubber stoppers with two 1/8" holes each, two plastic tubing about 2.5 ft long and 1/8" glass tube about 3 ft long. Glass tube will be cut on five pieces: 16", 13", 3" and two 3.1/2". From the 3.1/2" glass tube pieces make right angle bends with the side length 1.1/2". The 16" glass tube may be replace by metal tube of the same diameter. Insert two right angle bends into each of two rubber stoppers and then insert 16" fountain tube into second hole of these stoppers. The cup ***A*** of the fountain is made from the upper 1/3 part of the plastic soda bottle by cutting it. Setting the cup ***A*** upright, connect it and partially filled plastic soda bottle ***B*** mouth to mouth using two rubber stoppers with right angle bends and fountain tube. Insert 13" and 3" glass tubes into the third rubber stopper and place it into the empty plastic coda bottle ***C***. Finally connect the glass tubes of the bottle ***C*** and glass tube of bottle ***B*** and cup ***A*** with the plastic tubes. To start the fountain you should pour the glass of water into the cup ***A*** and stand the empty bottle ***C*** lower then one with water. The fountain works when leaks of water or air are escape. The magic fountain will act since all water of the upper bottle flows into the empty bottle. To restart the fountain you can replace the bottles and again pour water into the cup ***A***. The fountain works better and longer if the nozzle of the fountain tube is narrow. It spouts into the open air for a few minutes. For more impression use colored water or Coca-Cola. This dramatic presentation your whole class will love.

References:

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Este é um pedaço de um livro que nele conta sobre a Fonte de Heron e além disso trás algumas modificações que podem ser feitas. Pode ser encontrado na web completo.

water by it. How many ages have elapsed, and how many millions of people have witnessed this operation, without a useful idea having been derived from it? And without any one thinking that valuable lessons in science might be learnt from a disordered pump, or from the irregular movements of a pump handle? Those observing minds, however, that are constantly on the alert for facts—like bees incessantly on the wing for honey—would not now suffer even such an occurrence to pass unnoticed; nor would they hesitate to consider those unpleasant knocks which hundreds of people (and the writer among them) have occasionally experienced from the unexpected descent of a heavy pump handle on their persons, and in some instances more unpleasant ones from its sudden ascent—as admonitions to turn the experiment to advantage. The simple rise of water which his body displaced in a bathing tub, was seized in a twinkling by the mathematician of Syracuse to solve a new and difficult problem; yet the same thing had been previously witnessed for thousands of years, but no one ever thought of applying the result to any such purpose.

It perhaps may be a question whether the machines already described in this chapter were known to the engineers of antiquity, but there is no room to doubt their acquaintance with another variety of pressure engines, since we have obtained a knowledge of them from the Spiritalia of Heron, whose name they still bear. It is obvious that a liquid may be forced out of a vessel by pressing into the latter any other substance, no matter what the nature of it may be, whether solid or fluid, liquid or aëriform: thus, the solid plunger or piston of a pump does not more effectually expel the contents of the cylinder in which it moves, than the elastic fluid in a soda fountain drives out the aerated water; hence, if air be urged by the pressure of a liquid column, or by any other force, to occupy the interior of a vessel containing water, the liquid may be raised through a tube to an elevation equal to the force that moves it; the air in this case performing the part of pistons in the pressure engines already described; and its effects are greater than can be produced by solid pistons, for the friction of these consumes a considerable portion of the motive force, so that a column of water raised by them can never equal the one that raises it; whereas air, from its extreme mobility, receives and transmits the momentum of the motive column undiminished to the other.

The fountain of Heron is the oldest pressure engine known, and in it a volume of air is used as a substitute for a piston. It is not certain that it was invented by him, for it may have been an old device in his time, and one which he thought worthy of preservation, or of being made more extensively known, and therefore inserted an account of it in his book. See No. 163. The two vessels A B, of any shape, are made air tight. The top of the upper one is formed into a dish or basin; in the centre of which the jet pipe is inserted, its lower end extending to near the bottom of A: a pipe C, whose upper orifice is soldered to the basin extends down to near the bottom of the lower vessel, either passing through the top of B, as in the figure, or inserted at the side. Another pipe D is connected to the top of B, and continued to the upper part of A. This pipe conducts the *air* from B to A. Now suppose the vessel A filled with water, through an aperture made for the purpose, and which is then closed; the object is to make this water ascend through the jet, and it is accomplished thus:—water is poured into the basin, and of course it runs down the pipe C into B; and as it rises in the latter, the air within is necessarily compressed, and having no way to escape but up the pipe D, it ascends into the upper part of A, where being pressed on the surface of

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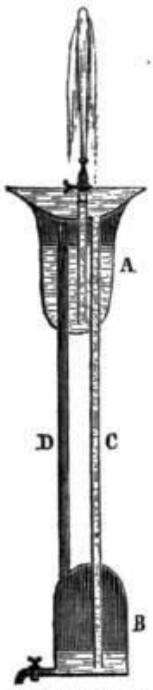
the water, the latter is compelled to ascend through the jet pipe, as shown in the cut. The water thus forced out, falls back into the basin, and running down C into B continues the play of the machine, until all the water in A is expended. The elevation to which water in A can be thus raised through a tube, will be equal to the perpendicular distance between the two orifices of C. To persons who are ignorant of the construction of these fountains, the water in the basin appears to descend, and to *rise again* through the jet. Such is not the fact; were it so, this machine would be a perpetual motion, or something very like one. Some persons beguiled by the apparent possibility of inducing it to ascend, have attempted the solution of that problem by a similar apparatus. We may as well confess that in our youth we were of the number. The younger Pliny seems to have fallen into the same mistake respecting a fountain belonging to his country seat.



No. 163. Heron's Fountain.

Portable fountains of this kind might be adopted as appropriate appendages to flower gardens, and even drawing rooms. The pipes might be concealed within, or modeled into a handsome column, whose pedestal formed the lower vessel, while the upper end assumed the figure of a vase. Such an addition to the furniture of an apartment would be a useful acquisition at those seasons when the atmosphere, glowing like the air of an oven, scorches our bodies during the day, and in the evening we gasp in vain for the cooling breeze: at such times a minute stream of water spouting and sparkling in a room would soon allay the heat and invigorate our drooping spirits—imparting the refreshing coolness of autumn amid the burning heats of summer; and if the liquid were perfumed with attar of roses, or oil of lavender, we might realize the most innocent and delicious of oriental luxuries. The play of such a fountain might be continued for two or three hours at a time, for the size of the stream need hardly exceed that of a thread, and by a slight modification, the jet could be renewed as often as the upper vessel was emptied, by simply inverting the machine: or, the whole might be arranged without, except the ajutage and the vase in which the jet played. (See remarks on fountains in the fifth book.)

This fountain has been named *a toy*, but it is by such toys that important discoveries have been made in every age. It is clearly no rude or imperfect device: not a first thought; on the contrary, it bears the evidence of a matured machine, and of being the result of a familiar acquaintance with the principles upon which its action depends. Unlike older hydraulic machines, it requires no distinct vessel within which to raise a a liquid; nor does it resemble pumps, since neither cylinders, suckers, valves or levers are required, nor any external force to keep it in motion.

Its invention may be considered as having opened a new era in the history of machines for raising water, for it is susceptible of an almost endless variety of modifications, and of being applied to a great number of purposes. To understand this it is only necessary to bear in mind that the relative position of the two columns is immaterial: they may be a mile distant from each other, or they may be nearly together. The one that raises the other may be above, below, or on a level with the latter; both may be conveyed in pipes along or under the surface of the ground, and in any direction: the only condition required is, that the perpendicular

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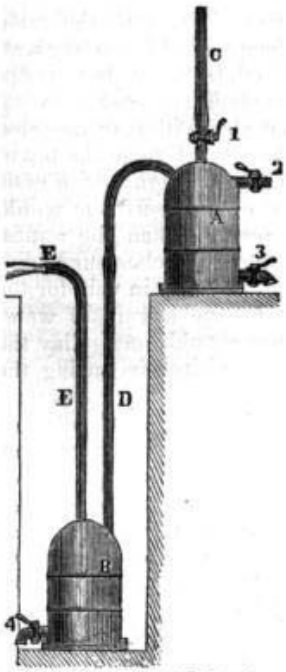
distance between the upper and lower orifices of the pipe in which the motive column flows, shall be equal to the force required to raise the other to the proposed elevation.

A pressure engine on the principle of Heron's fountain, erected by M. Hoell in 1755, to raise water from one of the mines in Hungary, has long been celebrated. In the vicinity of one of the shafts at Chemnitz, there is a hill upon which is a spring of water, one hundred and forty feet above the mouth of the shaft. This spring furnishes more water than that which rises at the bottom of the mine, which is one hundred and four feet below the mouth of the shaft. The water in the mine is raised by means of that on the hill by an apparatus similar to the one figured in the annexed cut.

A represents a strong copper vessel eight feet and a half high, five feet diameter, and two inches thick. A large cock marked 3 is inserted near the bottom, and a smaller one 2 near the top. From this vessel a pipe D, two inches in diameter, reaches down and is connected to the top of the vessel B at the bottom of the shaft. This vessel is smaller than the upper one, being six feet and a half high, four feet diameter, and two inches thick, and of the same material as the other. A pipe E, four inches diameter, rises from near the bottom of B to the surface of the ground, where it discharges the water. The pipe C conveys the water from the spring on the hill; it is also four inches diameter, and descends to near the bottom of A. It is furnished with a cock 1. Water is admitted into B through a cock 4, or a valve opening inwards, which closes when B is filled. The vessel A is supposed to be empty, or rather filled with air, and its two cocks shut. The cock 1 is then opened, when the water rushing into A condenses the air within it and the pipe D, and this air pressing on the water in B, forces it up the pipe E. As soon as it ceases to flow through E, the cock 1 is shut and 2 and 3 are opened, when the water in A is discharged at 3. The cock or valve at the bottom of B is opened, and the water entering drives the air up D into A where it escapes at 2. The operation is then repeated as before.



No. 164. Pressure Engine at Chemnitz.

If, when water ceases to run at E, the cock 2 be opened, both water and air rush out of it together, and with such violence that the liquid is, by the generation of cold consequent on the sudden expansion of the condensed air, converted into hail or pellets of ice. This fact is generally shown to strangers, who are usually invited to hold their *hats* in front of the cock so as to receive the blast; when the hail issues with such violence, as frequently to pierce the hats, like pistol bullets. This mode of producing ice was known to the marquis of Worcester, who refers to it in the eighteenth proposition of his Century of Inventions, relating to an "artificial fountain, holding great quantity of water, *and of force sufficient* to make snow, ice, and thunder." Some additions to the machine at Chemnitz, by which it might be rendered self-acting, were proposed in 1796. They consisted of small vessels suspended from levers that were secured

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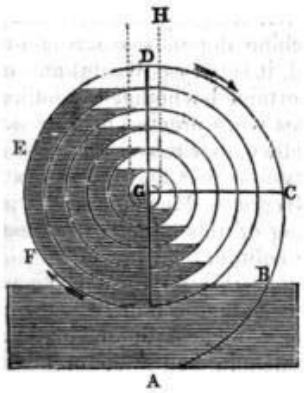
to the shanks of the cocks, which they opened and shut in the same manner as shown in No. 160. A similar contrivance may be seen in several old authors—it is in the Spiritalia: Decaus, Fludd, Moxon and Switzer have all given figures of it. The quantity of water raised from the shaft compared with that expended from the spring was as 42 to 100.

By arranging a series of vessels above each other and connecting them by pipes as in No. 163, water may be raised to almost any height, in locations that have the advantage of a small fall. The distance between the vessels not exceeding the perpendicular descent of the motive column, which last is made to transmit its force to each vessel in succession—forcing the contents of one into the next above, and so on. Such a machine is interesting as showing the extent to which the principle of Heron's fountain may be applied, but for practical purposes it is of little value. It is too complex (if made self-acting) and too expensive for common use; and it is far inferior to the water ram. It was described by Dr. Darwin, in his *Phytologia*, to which modern writers generally refer, but it is an old affair. It is figured by Moxon in his "Mechanick Powers," Lon. 1696, and is mentioned by older authors. It is substantially the same as the double fountain of Heron, as found in the Spiritalia and the works of most writers on hydraulics.

By far the most novel and interesting modification of Heron's fountain was devised in the year 1746 by *H. A. Wirtz*, a Swiss pewterer or tinplate worker of Zurich. It is sometimes named a spiral pump, and was made to raise water for a dye house in the vicinity of that city. What the circumstances were that led Wirtz to its invention we are not informed—whether it was suggested by some incident, or was the result of reasoning alone. It is represented in the illustrations Nos. 165 and 166, the first being a section and the latter an external view.



No. 165. Section of Wirtz's Pump.

No. 166. View of Wirtz's Pump.

Wirtz's machine consists either of a helical or a spiral pipe. As the former it is coiled round in one plane as A B C D E F in No. 165. As a spiral it is arranged round the circumference of a cone or cylinder, and then resembles the worm of a still. The interior end at G is united by a water tight joint to the ascending pipe H. See No. 166. The open end

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of the coil is enlarged so as to form a scoop. When the machine, immersed in water as represented, is turned in the direction of the arrow, the water in the scoop, as the latter emerges, passes along the pipe driving the air before it into G H, where it escapes. At the next revolution both air and water enter the scoop; the water is driven along the tube as before, but is separated from the first portion by a column of air of nearly equal length. By continuing the motion of the machine another portion of water and another of air will be introduced. The body of water in each coil will have both its ends horizontal, and the included air will be of about its natural density; but as the diameters of the coils diminish towards the centre, the column of water which occupied a semicircle in the outer coil, will occupy more and more of the inner ones as they approach the centre G, till there will be a certain coil, of which it will occupy a complete turn. Hence it will occupy more than the entire space within this coil, and consequently the water will run back over the top of the succeeding coil, into the right hand side of the next one and push the water within it backwards and raise the other end. As soon as the water rises in the pipe G H, the escape of air is prevented when the scoop takes in its next quantity of water. Here, then, are two columns of water acting against each other by hydrostatic pressure, and the intervening column of air. They must compress the air between them, and the water and air columns will now be unequal. This will have a general tendency to keep the whole water back and cause it to be higher on the left or rising side of each coil, than on the other. The excess of height will be just such as produces the compression of the air between that and the preceding column of water. This will go on increasing as the water mounts in H. Now at whatever height the water in H may be, it is evident that the air in the small column next to it will always be compressed with the weight of the water in H—an equal force must therefore be exerted by the water in the coils to support the column in H. This force is the sum of all the differences between the elevation of the inner ends of the water in each coil above the outer ends; and the height to which the water will rise in H will be just equal to this sum. Dr. Gregory observes that the principles on which the theory of this machine depends are confessedly intricate; but when judiciously constructed, it is very powerful and effective in its operation. It has not been ascertained whether the helical or spiral form is best. Some of these machines were erected in Florence in 1778. In 1784, one was made at Archangelsky, that raised a hogshead of water in a minute to an elevation of seventy-four feet, and through a pipe seven hundred and sixty feet long. See Gregory's Mechanics, vol. ii.

It perhaps may facilitate an understanding of this curious machine, by remarking that the pressure exerted by the column of water in one side of each coil is proportioned to its length, and that this pressure is transmitted, through the column of air between them, to that of the next: the combined force of both is then made to act, by the revolution of the tubes, upon the third column, and so on, till the accumulated force of them all is communicated to the water in H; and hence the elevation to which water can be thus raised, can never exceed the sum of the altitudes of the liquid columns in the coils.

END OF THE THIRD BOOK.

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