**Docket #:** S15-444

# Paperfuge: a low-cost, high-speed, human-powered centrifuge

Researchers at Stanford have developed the paperfuge- an ultra-low cost (20 cents), light weight (2g) field portable centrifuge (125,000 rpm; 30,000 g RCF) made out of paper that runs on human power. Sample preparation, including separation of plasma from whole blood or isolation of parasites, is an unmet challenge in many point of care (POC) diagnostics and requires centrifugation as the first key step. From the context of global health applications, commercial centrifuges are expensive, bulky and electricity-powered; leading to a critical bottle-neck in the development of decentralized, electricity-free POC diagnostic devices. By uncovering the fundamental mechanics of an ancient whirligig toy (3300 B.C.E), the inventors designed an ultra-low cost (20 cents), light-weight (2 g), human-powered centrifuge that is made out of paper ("paperfuge"). To push the operating limits of this unconventional centrifuge, they presented an experimentally-validated theoretical model that describes the paperfuge as a non-linear, non-conservative oscillator system. The inventors used this model to inform their design process, achieving speeds of 125,000 rpm and equivalent centrifugal forces of 30,000 g, with theoretical limits predicting one million rpm. They harnessed these speeds to separate pure plasma in less than 1.5 minutes and isolate malaria parasites in 15 minutes from whole human blood. By expanding the materials used, the inventors implemented centrifugal microfluidics using PDMS, plastic and 3D-printed devices, ultimately opening up new opportunities for electricity-free POC diagnostics, especially in resource-poor settings. This technology provides a much needed centrifugation tool for POC diagnostics in resource poor settings and the simplicity of manufacturing the paperfuge will enable immediate mass distribution.

Using paperfuge to separate plasma from whole blood

**Stage of research**
The inventors have already demonstrated the utility of the Paperfuge for diagnostic applications by separating plasma from human blood in 1.5 minutes, with no user fatigue; and separation of malaria parasites. Field testing in resource poor settings is currently under way.

# Applications

- Centrifugation of biological samples for:
    - Medical assays- including hematocrit (anemia detection)
    - Point-of-care diagnostics- including malaria, African trypanosomiasis and numerous other diagnostics applications
    - Lab and field research; ecological sample collection and preservation
    - Versatile scientific tools for education and outreach

# Advantages

- Low-cost- costs less than $0.20 (bill of materials) (traditional centrifuges cost $100-$1000)
- Electricity free- operates on human power
- Paper-based:
    - Light weight- 2 grams
    - Easy disposal- dispose of infectious sample and centrifuge by incineration
    - Print-manufacture
    - Embedded microfluidics for complex “centrifugal microfluidics” without the need for electricity
- High rotational speeds- achieves speeds in excess of 100,000 rpm
- High relative centrifugal forces (RCF)- achieves 30,000 g
- Can process sample in 2 minutes or less (half the time required by commercial centrifuges to separate plasma from blood)
- Requires almost no training- can be operated by health workers or patients themselves with minimal user fatigue
- Allows integrated paper or polymer based microfluidics
- Plastic/injection molded variants
- Potential for use in one-step diagnostics that combine sample prep, microfluidics and diagnostics

- Can be rapidly deployed for point-of-care diagnostics
- Easy to carry; highly robust, waterproof

## Publications

- M. Saad Bhamla, Brandon Benson, Chew Chai, Georgios Katsikis, Aanchal Johri, Manu Prakash. Paperfuge: An ultra-low cost, hand-powered centrifuge inspired by the mechanics of a whirligig toy. Biorxiv. Posted August 30, 2016.
- Newby, Kris. "Inspired by a whirligig toy, Stanford bioengineers develop a 20-cent, hand-powered blood centrifuge." Stanford News, Jan. 11, 2017.

## Patents

- Published Application: 20190022642
- Issued: 11,331,665 (USA)

## Innovators

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