Rheology Comics #1

Rheology is the study of how things flow (*rheo* = flow, *logos* = study).

Panta rhei – everything flows!

Inspired by M.A. Fardin's Ig Nobel Prize winning article "On the rheology of cats" (2014), this comic describes the fundamentals of rheology with the aid of our favorite felines.

Funded by the Society of Rheology's 2023 Rheology Venture Fund.

Learn more about rheology by following the QR code.

This comic is also available in:

Ελληνικά • 日本語

Français • فارسی

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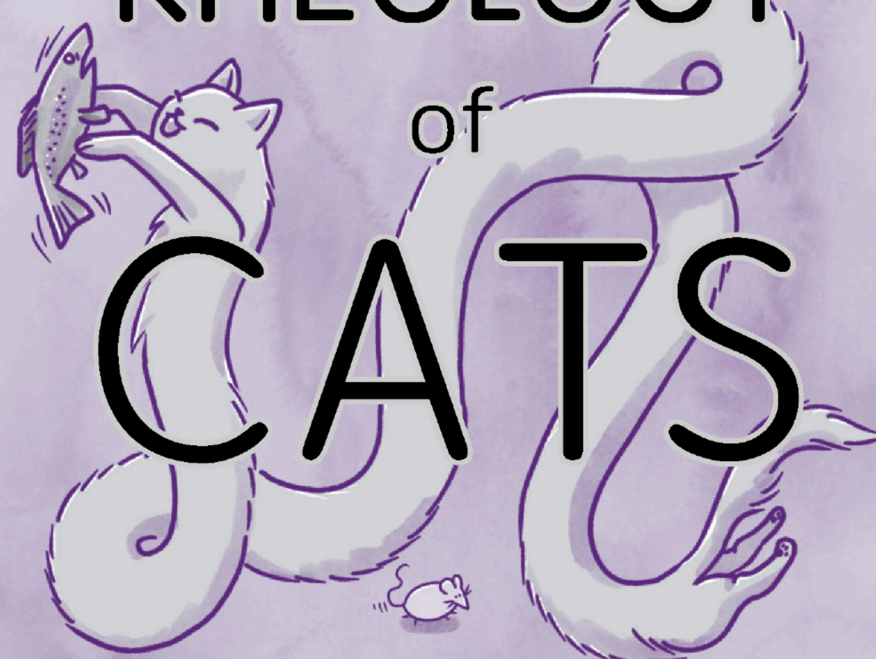
And more coming soon!

Are cats solid or liquid?

RHEOLOGY of CATS



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Victoria Russell and Kelsey Briselli.

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v1.2

GLOSSARY

RHEOLOGY – the study of how things flow in different situations (especially materials that are not purely solid, liquid, or gas)

STRESS – the amount of force applied to a material

STRAIN – how much a material changes its shape

ELASTIC SOLID – a material that holds its shape and will bounce back to its original shape after experiencing stress

PLASTIC SOLID – a material that holds its shape but does not bounce back to its original shape after experiencing stress

YIELD STRESS – the maximum amount of stress an elastic material can experience before becoming plastic

BROKEN SOLID – a material that holds its shape but has cracked, fractured, or torn apart

VISCOUS LIQUID – a material that flows and takes the shape of its container

VISCOSITY – how "thick" a material is; a measure of the relationship between stress and strain-rate. It tells us how much stress you need to change how fast the material is moving

STRAIN RATE – how quickly the strain is changing; how quickly a material is moving and changing shape

VISCOPLASTIC – behaving like a plastic solid at low stress and a viscous liquid at high stress (ex: mud, toothpaste, mayonnaise)

VISCOELASTIC – having a strain-rate that depends on time: elastic behavior over short times, viscous flow over long times (ex: a pile of noodles, ketchup)

ELASTOPLASTIC – having a yield stress: being elastic at low stress and plastic at high stress (ex: steel)

ELASTOVISCOPLASTIC – changing behavior depending on both the amount of strain and the strain rate (ex: lava)

SHEAR THICKENING – when the viscosity increases as the shear rate increases, and large stresses can cause small strains

SHEAR THINNING – when the viscosity decreases as the shear rate increases, and small stresses can cause large strains

THIXOTROPY – when the same stress causes different behavior over time; a "time delay" or "memory" effect usually caused by the material's internal structure

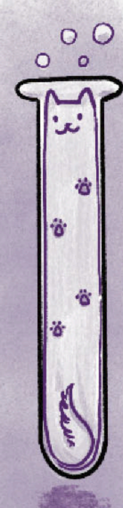
WEISSENBERG EFFECT – when stirring a material, it climbs up the stirrer instead of flying away from it

DIE SWELL – when flowing out of a faucet or a container, the material briefly expands in size

So what are cats?

We may never fully understand why cats behave the way they do, but we know they follow their own rules, just like lots of materials do.

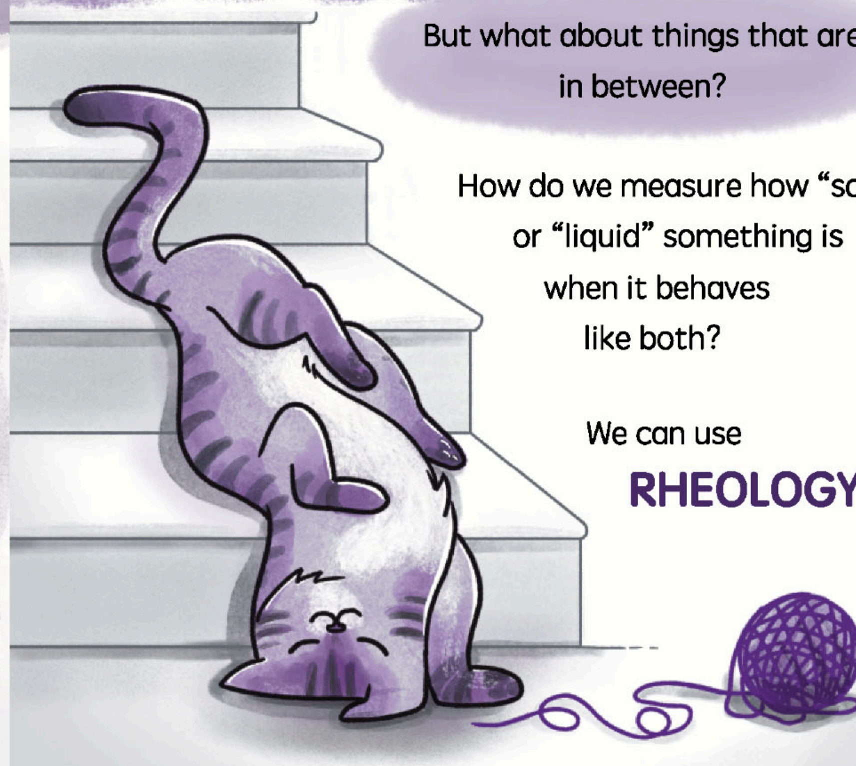
There's still a lot we don't understand about materials in between solid and liquid. Rheology shows us that these complex behaviors depend on the relationship between stress and strain, and how those things change over time.
But every material is a little bit different, just like every cat!



Which one is your favorite?

Are cats solid or liquid?
We know the three main states of matter:

Solids hold their shape. Liquids and gasses take the shape of their container.



But what about things that are in between?

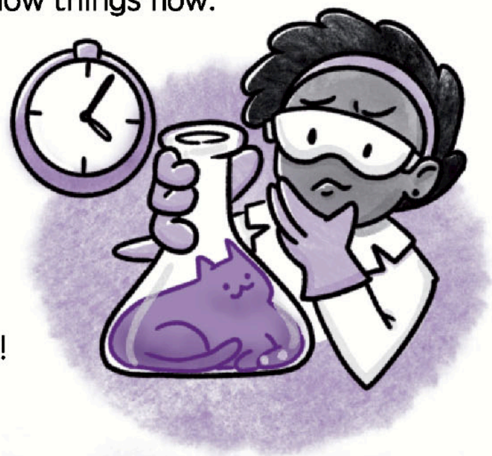
How do we measure how "solid" or "liquid" something is when it behaves like both?

We can use

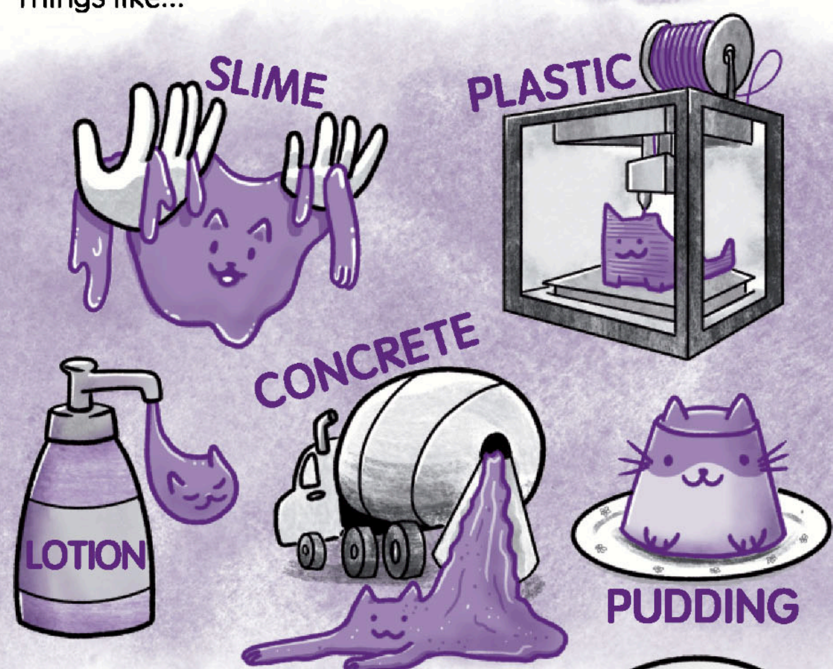
RHEOLOGY!

Rheology is the study of how things flow.

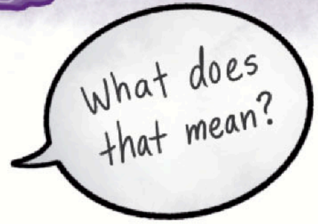
A rheologist studies how "solid" or "liquid" something is, and uses that information to customize materials with special squishy properties!



Things like...



Rheologists measure how a material behaves over time by looking at **stress** and **strain**.



Usually when you stir a fluid really fast, it flies out in all directions (like eggs in a mixer), but some materials will cling to the mixer like a cat, and even climb up it!

This is called the

WEISSENBERG EFFECT

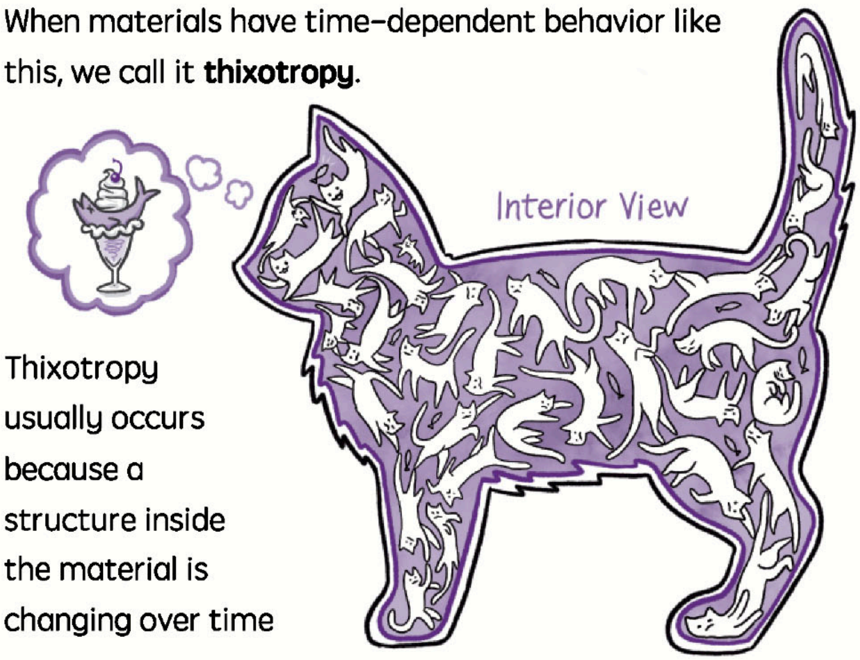
Water flows out of a faucet pretty smoothly, but some viscoelastic fluids will change size, expanding to be a lot bigger right as they leave a container.

This is called

DIE SWELL

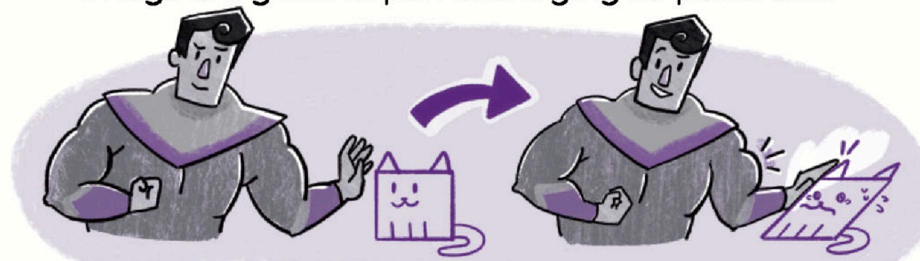
If you apply the same stress at the same rate for a long time, sometimes the cat's behavior changes! Like there's a time delay while the cat decides how to react to the stress.

When materials have time-dependent behavior like this, we call it **thixotropy**.



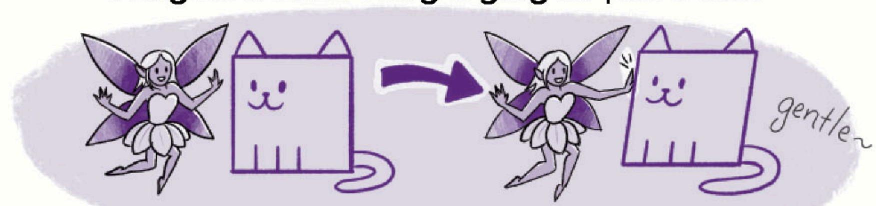
Thixotropy usually occurs because a structure inside the material is changing over time

Imagine a giant superhero trying to pet a cat.



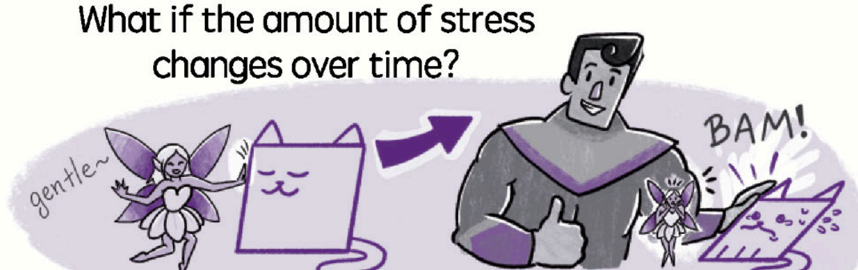
The force of that pet is called the **stress**.
The cat being squished (changing its shape) is called the **strain**. A large stress causes a large strain.

Imagine a little fairy trying to pet a cat.



Because there's very little stress, there's very little strain on the cat. A small stress causes a small strain.

What if the amount of stress changes over time?



How stress and strain change over time, and whether it happens quickly or slowly, is important in rheology.

Usually the stress and strain change together – the bigger the stress, the bigger the strain – but not always! More on that later.

What does this have to do with solids and liquids??

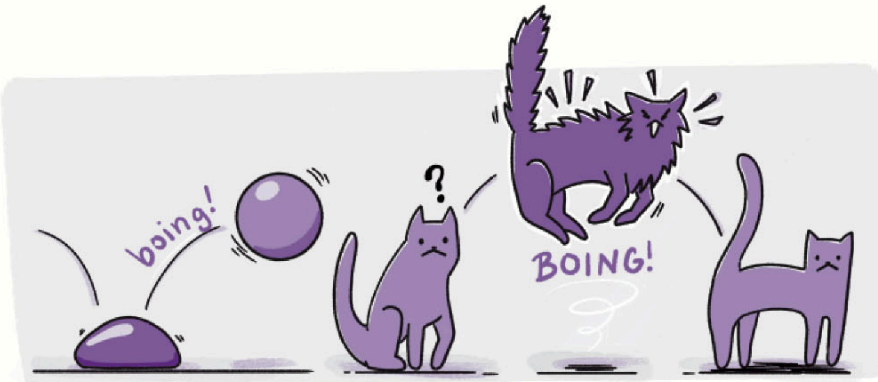
Let's start with solids.

Over short times, cats behave like a solid.

They can be:

ELASTIC PLASTIC BROKEN.

When cats are startled, they are like an **elastic** solid.

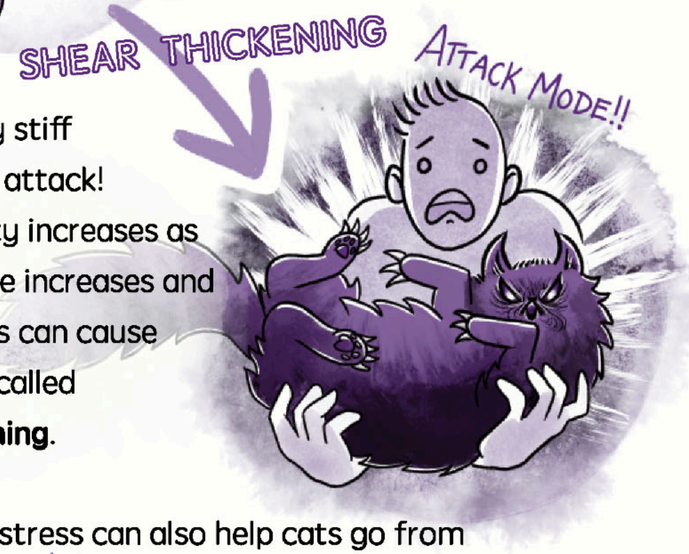


Like a rubber ball, cats **"**bounce back**"** to their original shape after experiencing stress and strain.

That ability to return to their original shape is called **"**elasticity.**"**

Sometimes more stress doesn't equal more strain.

If you increase the amount of stress on a cat, it doesn't always increase the amount of strain. Instead the cat can switch from being relaxed...



...to suddenly stiff and ready to attack! Their viscosity increases as the shear rate increases and large stresses can cause small strain, called **shear thickening**.

But applying stress can also help cats go from stiff to super chill...

Their viscosity decreases as the shear rate increases and small stresses can cause large strain, called **shear thinning**.

Lots of things have a combination of elastic, plastic, and viscous behavior, just like cats.

VISCOPLASTIC

A plastic solid at low stress, and a viscous liquid at high stress

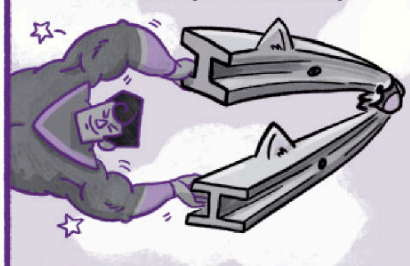
(ex: mud, toothpaste, mayonnaise)

VISCOELASTIC

Strain-rate depends on time: elastic behavior over short times, viscous flow over long times

(ex: a pile of noodles, ketchup)

ELASTOPLASTIC



Solids with a yield stress: elastic at low stress, plastic at high stress

(ex: steel)

ELASTOVISCOPLASTIC

Behavior depends on both the amount of strain and the strain rate

(ex: lava)

Their behavior depends on complicated relationships between stress and strain, and so they do things that seem unexpected and unpredictable!

Some solids, like clay, don't bounce back. Instead stress on a **plastic** solid stretches or smushes it. It stays that way until a new stress is applied.

This ability to change shape is called "plasticity."

Cats start off elastic until they reach a **yield stress**, the amount or rate of stress that causes them to stop bouncing back and become plastic.

But if you apply too much stress to any solid...

...eventually it will still **break**.

Over a longer period of time cats behave like a liquid, taking the shape of their container.

Compared to water, cats are more **viscous** – they're a bit thicker.

They have a higher **viscosity** and flow more slowly like honey or molasses.

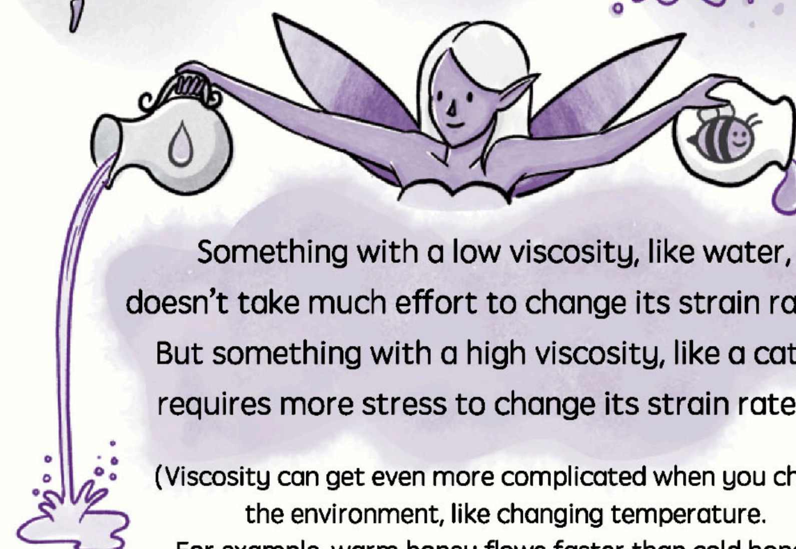
A low viscosity liquid is thinner, and flows quickly like water or milk.

How do we look at the relationship between stress and strain in a liquid? It's hard!

Liquids are always moving, so the amount of strain is always changing.

Instead we can look at how quickly the strain is changing. How fast is the liquid changing shape? This is called the **strain rate**.

Viscosity tells us the relationship between stress and strain rate. It tells us how much stress you would need to change how fast the liquid is moving.



Something with a low viscosity, like water, doesn't take much effort to change its strain rate. But something with a high viscosity, like a cat, requires more stress to change its strain rate.

(Viscosity can get even more complicated when you change the environment, like changing temperature. For example, warm honey flows faster than cold honey.)