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# A Numerical Study of Oblique Stagnation Point Flow of Ternary Nanofluid over a Stretching Sheet

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## Abstract

A mathematical model has been developed to investigate the heat transfer enhancement due to the ternary nanofluid ($Cu/Fe_3O_4/SiO_2$-Polymer) flow past a stretching sheet. A time-independent two-dimensional oblique stagnation-point flow was considered. The governing equations for the conversion of mass, momentum and energy along with the boundary conditions were transformed into dimensionless equations using relevant non-dimensional variables. The obtained set of equations was reduced to ordinary differential equations using similarity transformations. A numerical technique was used to find the solution and validate the attained results with the existing literature in a limiting case. The solutions were presented graphically for fluid velocity and temperature for various volume fractions of the nanoparticles. The results were analysed for different cases of nanofluid, hybrid nanofluid and ternary nanofluid.

**Keywords:** Hybrid Nanofluid, Nanofluid, Oblique Stagnation Point, Stretching Sheet, Ternary Nanofluid

## 1.0 Introduction

About two decades ago typical fluids like water, ethylene glycol and oil were used as coolants to avoid overheating of systems like automobile engines, machines used in industries, electronic devices etc. for better performance. However, due to low heat transfer properties, they didn't stand out as an effective coolant. An experimental study was also carried out to measure the heat conduction ability of the fluid containing oxide nanoparticles and the results showed that the fluid containing nanoparticles has significantly higher heat transfer rates than the base fluid. This fluid with nanoparticles was termed Nanofluid ( Lee S. *et al*)[1].

Advancement in the field of engineering has led to a high demand for improving the cooling and heat transfer abilities of the fluid used in the system for better performance. Jha and Ramaprabhu[2] carried out research on heat transfer ability by using a hybrid of Silver (Ag) and Multi-Walled Carbon Nanotubes (MWCNs) and the results showed that thermal conductivity increased significantly when compared to the nanofluids. The base fluid with more than one type of nanoparticle suspended was termed Hybrid nanofluid**.** The mixture of three different nanoparticles suspended in the base fluid was termed Ternary nanofluid. With this, the below literature review throws light on Ternary nanofluids.

An experimental study was conducted by taking Copper Oxide, Magnesium Oxide and Titanium Dioxide ($CuO/MgO/TiO_{2)}$ aqueous ternary nanofluid and the results showed that ternary fluid has significantly better heat transfer ability than the corresponding hybrid nanofluid

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(with two different particles) and nanofluids (Mousavi *et al*[3]). A numerical study was carried out on heat transfer ability and velocity by taking the ternary hybrid nanofluid – $TiO_2$/$Al_2O_3$/$SiO_2$ -glycol/$H_2O$ and the outcome was the addition of ternary nanoparticles to the base fluid boosts the velocity and heat transfer rate (Bilal *et al*[4]). An experimental study of the heat conduction ability of a ternary nanofluid consisting of MWCNTs- titanium-zinc oxide/ Ethylene Glycol (EG) - water (20:80) as well as binary and mono nanofluids revealed that thermal conductivity increases with increase in volume fraction (Boroomandpour A. *et al*[5]). Sahoo RR[6] investigated the heat transfer ability of ternary hybrid nanofluid with unique shapes-cylindrical (CNT), blade ($Al_2O_3$) and platelet (graphene)/ water and the investigation revealed that concentrations and the shape of nanoparticles play a main role in the enhancement of the thermal performance. Sahoo RR[7] investigated the heat transfer ability of ternary nanofluid with unique shapes- cylindrical (CNT), spherical (CuO), and platelet (graphene)/water and the investigation revealed that concentrations and the shape of nanoparticles play a main role in the enhancement of the thermal performance. Zayan *et al.*,[8] studied the influence of nanoparticles' volumetric fraction and temperature on the rheological properties of water-based GO-$TiO_2$-Ag and rGO-$TiO_2$-Ag ternary nanofluids. Mahmood Z. and Khan U.[9] investigated the influence of magnetic field strength and the mass suction with ohmic heating near the stagnation region of stretching/ shrinking cylinder of Cu/$Fe_3O_4$/$SiO_2$-Polymer ternary hybrid nanofluid flow in two-dimensions with nanoparticle shape effect.

The stagnation point is the point about which the fluid splits and moves in both directions. The oblique stagnation point is the point where fluid entry is not orthogonal to the channel. Labropulu *et al.*,[10] have examined the velocity and temperature of time-independent 2D non-orthogonal stagnation-point flow of a second-grade fluid with viscoelastic property over a stretching sheet with transfer of heat. Lok *et al.*,[11] investigated the time-independent MHD (Magneto Hydrodynamics) non-orthogonal stagnation-point flow of an electrically conducting and viscous fluid over a stretching/shrinking sheet. Ghaffari A. *et al.*,[12] discussed the improvement of the heat transfer ability of viscoelastic fluid with suspended nanoparticles because of consideration of radiation and convective boundary conditions in oblique stagnation point flow over a stretching sheet. Mehmood *et al.*,[13] investigated the collective effect of thermal radiation and mixed convection on non-aligned Casson fluid flowing over a stretching sheet. Sajid M *et al.*,[14] applied a spectral collocation procedure based on Legendre wavelet to understand the radiation and slip effects in the oblique stagnation point flow of a viscoelastic Walters-B fluid over a sheet stretching linearly. Awan *et al.*,[15] numerically studied the two-dimensional non-orthogonal stagnation point flow of an incompressible time-dependent Jeffrey fluid with the magnetohydrodynamic effects caused by an oscillatory and stretching sheet. Ramzan *et al*[16]., carried out a comparative study of the heat transfer abilities of two nanofluids (SWCNHs/water and MWCNTs/water) with steady oblique stagnation-point flow over a stretching sheet driven by nonlinear thermal radiation using the Xue model.

Based on the above literature, the authors found the gap between the literature and the requirements of the industries and aimed to investigate the oblique stagnation point flow of ternary hybrid nanofluid (Cu/$Fe_3O_4$/$SiO_2$-Polymer) over a stretching surface in this paper. The importance of the proposed topic is noticed in the engineering field, mainly in the extrusion process of manufacturing industries.

## 2.0 Mathematical Formulation

The two-dimensional time-independent oblique stagnation point flow of ternary nanofluid over a stretching sheet is considered as shown in Figure 1. The fluid considered here is Newtonian, which is viscous and incompressible.

The governing equations of the flow are given by

### 2.1 Conservation of Mass (Continuity equation)

$$\frac{\partial u^*}{\partial x^*}+\frac{\partial v^*}{\partial y^*}=0 \tag{1}$$

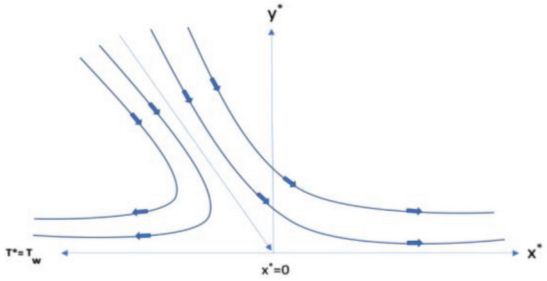



**Figure 1:** Oblique stagnation point fluid flow over a stretching sheet.

**Momentum Equations**

$$A\rho_f\left(u^*\frac{\partial u^*}{\partial x^*}+v^*\frac{\partial u^*}{\partial y^*}\right)=-\frac{\partial p^*}{\partial x^*}+B\mu_f\nabla^{*2}u^* \quad (2)$$

$$A\rho_f\left(u^*\frac{\partial v^*}{\partial x^*}+v^*\frac{\partial v^*}{\partial y^*}\right)=-\frac{\partial p^*}{\partial y^*}+B\mu_f\nabla^{*2}v^* \quad (3)$$

**Conservation of Energy**

$$u^*\frac{\partial T^*}{\partial x^*}+v^*\frac{\partial T^*}{\partial y^*}=C\alpha_f\nabla^{*2}T^* \quad (4)$$

$u^*\left(x^*,y^*\right)$, $v^*\left(x^*,y^*\right)$ are velocity components, $p^*\left(x^*,y^*\right)$ is fluid pressure function, $T^*$ is the fluid temperature function, $\alpha_f$ is the thermal diffusivity of the base fluid, $\mu_f$ is the dynamic viscosity of the base fluid, $\rho_f$ is the constant density of the base fluid. A, B and C are dimensionless constants which are given by $A=\frac{\rho_{Tnf}}{\rho_f}$, $B=\frac{\mu_{Tnf}}{\mu_f}$ $and\ C=\frac{\alpha_{Tnf}}{the\,\alpha_f}$ where $\rho_{Tnf}$ is the constant density of the ternary nanofluid, $\mu_{Tnf}$ Is dynthe amic viscosity of the ternary nanofluid, $\alpha_{Tnf}$ is the thermal diffusivity of the ternary nanofluid. Star (*) on the variable and operators indicate dimensional form.

**Boundary Conditions**

Since the fluid flow is over the upper side stretching sheet, we have $y^*>0$ As the sheet is stretched about the oblique stagnation point on either side in an outward direction the boundary conditions are given by

$$u^*=cx^*,\ v^*=0,\ \ T^*=T_w \text{ on the plane } y^*=0 \quad (5)$$

$$u^*=ax^*+by^*,\ T^*=T \text{ as } y^*\to\infty$$

**Where:**

a, b, c are constants and are greater than zero, $T_w$ is the wall temperature of the stretching sheet, $T$ is the ambient temperature of the fluid.

By making use of the below dimensionless variables

$$x=x^*\sqrt{\frac{c}{v_f}},\quad y=y^*\sqrt{\frac{c}{v_f}},\quad u=u^*\frac{1}{\sqrt{cv_f}}$$

$$v=v^*\frac{1}{\sqrt{cv_f}},\quad p=p^*\frac{1}{\rho_f v_f c},\quad T=\frac{T^*-T_\infty}{T_w-T_\infty}$$

the governing equations change to

## 2.2 Conservation of Mass (Continuity Equation)

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (7)$$

**Momentum Equations**

$$A\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)+\frac{\partial p}{\partial x}=B\nabla^2u \quad (8)$$

$$A\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)+\frac{\partial p}{\partial y}=B\nabla^2v \quad (9)$$

**Conservation of Energy**

$$Pr_f\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=C\nabla^2T \quad (10)$$

where $Pr_f=\frac{v_f}{\alpha_f}$ is the Prandtl number of the base fluid.

Using the equation of continuity, we define the stream function. $\psi\left(x,y\right)$ such that

$$u=\frac{\partial\psi}{\partial y} \text{ and } v=-\frac{\partial\psi}{\partial x} \quad (11)$$

Substituting (11) in (8) and (9) and using the relation of the partial derivative of the pressure function.

$\left(\frac{\partial^2p}{\partial x\partial y}=\frac{\partial^2p}{\partial y\partial x}\right)$, we get

$$A\left[\frac{\partial\left(\psi,\nabla^2\psi\right)}{\partial\left(x,y\right)}\right]+B\nabla^4\psi=0 \quad (12)$$

Substituting (11) in (10), we get

$$Pr_f\left(\frac{\partial\psi}{\partial y}\frac{\partial T}{\partial x}-\frac{\partial\psi}{\partial x}\frac{\partial T}{\partial y}\right)=C\nabla^2T \quad (13)$$

Substituting (11) in boundary conditions (5) & (6), we get the dimensionless boundary conditions as

$$u=x,\quad v=0,\quad \psi=0,\quad T=1 \text{ at } y=0 \quad (14)$$

$$\psi = \frac{a}{b}xy + \frac{b}{2c}y^2, \quad T = 0 \text{ as } y \to \infty \tag{15}$$

Considering the solutions for stream function and temperature as

$$\psi(x,y) = x.f(y) + g(y), \; T = \theta(y) \tag{16}$$

**Where:**

*f* is the normal component of the flow.

*g* is the tangential component of the flow.

By substituting equations (16) in equations (12), and (13) and then integrating them once, we get the following ODEs representing Momentum equations.

$$Bf''' + Aff'' - A(f')^2 + C_1 = 0 \tag{17}$$

$$Bg''' + Afg'' - Af'g' + C_2 = 0 \tag{18}$$

**Boundary conditions:**

$$f(0) = 0, \quad g(0) = 0, \quad f'(0) = 1, \quad g'(0) = 0, \quad \theta(0) = 1 \text{ at } y = 0 \tag{19}$$

$$f'(\;) = \frac{a}{c}, \quad g''(\;) = \frac{b}{c}, \quad \theta(\;) = 0 \text{ at } y \to \infty \tag{20}$$

By using boun and solving it we get

$$C_1 = A\left(\frac{a}{c}\right)^2.$$

A analysis of the boundary layer equation (17) implies that. $f(y)$ behaves as $f(y) = \left(\frac{a}{c}\right) + A_1$ as $y \to \infty$, where $A_1 = A_1\left(\frac{a}{c}\right)$ is constant that indicates boundary layer displacement. By using boundary condition (20) in equation (18) and solving it, we get $C_2 = -A_1 A\left(\frac{b}{c}\right)$. By substituting in equations (17) and (18), we get

$$Bf''' + Aff'' - A(f')^2 + A\left(\frac{a}{c}\right)^2 = 0 \tag{21}$$

$$g''' + Afg'' - Af'g' - A_1 A\left(\frac{b}{c}\right) = 0 \tag{22}$$

By using equation (16) in equation (10), we get the following ODE representing the Energy equation.

$$C\theta'' + Pr_f f\theta' = 0 \tag{23}$$

**Where:**

$$A = \frac{\rho_{Tnf}}{\rho_f}, \; B = \frac{\mu_{Tnf}}{\mu_f} \text{ and } C = \frac{\alpha_{Tnf}}{\alpha_f}$$

**Equations for thermophysical properties of nanofluid, hybrid nanofluid and ternary nanofluid (Mahmood Z. and Khan U.[9], Sohail *et al.*,[17])**

- $\rho_{Tnf} = (1-\Phi_1)\{(1-\Phi_2)[(1-\Phi_3)\rho_f + \Phi_3\rho_3] + \Phi_2\rho_2\} + \Phi_1\rho_1$
- $\mu_{Tnf} = \frac{\mu_f}{(1-\Phi_1)^{2.5}(1-\Phi_2)^{2.5}(1-\Phi_3)^{2.5}}$
- $\frac{k_{Tnf}}{k_{hnf}} = \frac{k_1+2k_{hnf}-2\Phi_1(k_{hnf}-k_1)}{k_1+2k_{hnf}-\Phi_1(k_{hnf}-k_1)}$
- $\frac{k_{hnf}}{k_{nf}} = \frac{k_2+2k_{nf}-2\Phi_2(k_{nf}-k_2)}{k_2+2k_{nf}-\Phi_2(k_{nf}-k_2)}$
- $\frac{k_{nf}}{k_f} = \frac{k_3+2k_f-2\Phi_3(k_f-k_3)}{k_3+2k_f-\Phi_3(k_f-k_3)}$
- $\frac{(\rho C_p)_{Tnf}}{(\rho C_p)_f} = \Phi_1\frac{(\rho C_p)_1}{(\rho C_p)_f} + (1-\Phi_1)[(1-\Phi_2)\{(1-\Phi_3) + \Phi_3\frac{(\rho C_p)_3}{(\rho C_p)_f}\} + \Phi_2\frac{(\rho C_p)_2}{(\rho C_p)_f}]$

## 3.0 Numerical Procedure for Solution

As the ODEs (21), (22) and (23) with boundary conditions (19) and (20) are non-linear, it is difficult to find the exact solution. Therefore, one of the accurate computational techniques called Bvp5c is used. First, we convert the higher-order equations into first-order equations by assuming f = y (1), f ′ = y (2), f ′′ = y (3), g = y (4), g′ = y (5), g′′ = y (6), θ = y (7), θ′ = y (8), by this we get

$$\frac{d}{dy}\left[y(1)y(2)y(3)y(4)y(5)y(6)y(7)y(8)\right] = \begin{bmatrix} y(2)y(3)\left(-\frac{A}{B}\right) * y(1) * y(3) \\ +\left(\frac{A}{B}\right) * \left(y(2)^2\right) - \left(\frac{A}{B}\right) * \left(\frac{a^2}{c^2}\right) y(5)y(6) \\ -\left(\frac{A}{B}\right) * y(1) * y(6) + \left(\frac{A}{B}\right) * y(5) * y(2) \\ +\left(\frac{A}{B}\right) * A1 * \left(\frac{b}{c}\right) y(8)(-Prf / C1) * y(1) * y(8) \end{bmatrix} \tag{24}$$

**Table 1.** Ternary nanoparticles and polymer (thermophysical properties) – Mahmood Z and Khan U[9]

| Properties | Cu($\Phi_1$) | $Fe_3O_4$($\Phi_2$) | $SiO_2$($\Phi_3$) | Polymer |
|---|---|---|---|---|
| p(kg/m$^3$) | 8933 | 5180 | 2650 | 1060 |
| Cp(J/kgK) | 385 | 670 | 730 | 3770 |
| k(W/mK) | 401 | 9.7 | 1.5 | 1.429 |
| Pr | | | | 6.2 |

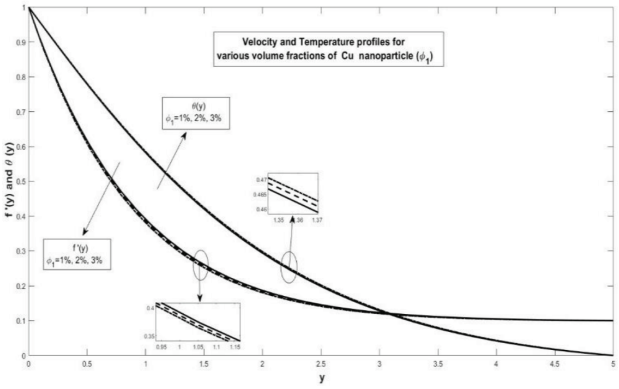



**Figure 2:** Velocity and Temperature profiles for different volume fractions of Cu ( $\Phi_1 = 1\%, 2\%, 3\%$ )

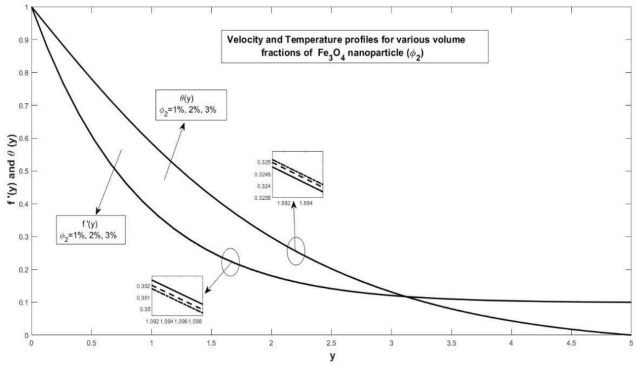



**Figure 3:** Velocity and Temperature profiles for different volume fractions of $Fe_3O_4$ ( $\Phi_1 = 1\%, 2\%, 3\%$ )

Equation (24) is a boundary value problem in vector form [y(1), y(2), y(3), y(4), y(5), y(6), y(7), y(8)]

## 4.0 Results and Discussions

The effect of volume fraction of each type of nanoparticle (Cu, $Fe_3O_4$, $SiO_2$) on velocity and temperature of the ternary hybrid nanofluid and comparison of profiles of velocity and temperature between base fluid, nanofluid, hybrid nanofluid and ternary nanofluid has been investigated in this study.

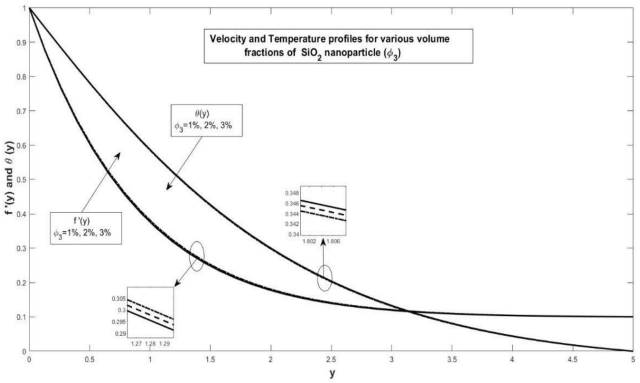



**Figure 4:** Velocity and Temperature profiles for different volume fractions of $Si0_2$ ( $\Phi_1 = 1\%, 2\%, 3\%$ )

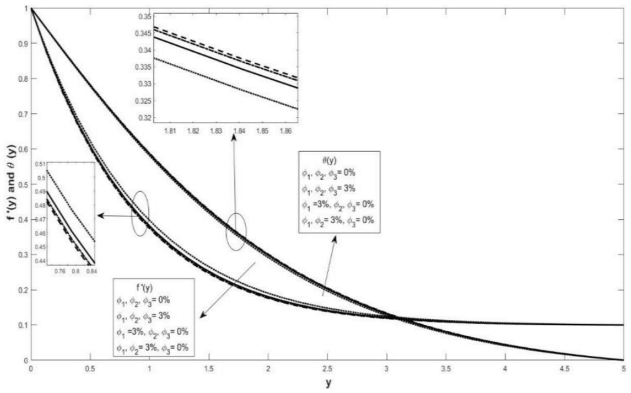



**Figure 5:** Velocity and Temperature profiles for different fuilds: base nanofluid, hybrid nanofluid and ternary nanofluid.

**Case 1:** Impact of volume fraction of Cu ( $\Phi_1$ ) on the velocity and temperature are studied. It is noticed that the increment in volume fraction leads to a significant decrement in the velocity and increment in the temperature as shown in Figure 2. That is, the heat transfer ability of ternary nanofluid with $\Phi_1 =$ 3% is higher than ternary nanofluids with $\Phi_1 =$ 1% and 2% .

**Case 2:** Effect of volume fraction of $Fe_3O_4$ ( $\Phi_2$ )on the velocity and temperature investigated, it is noticed that as the volume fraction increases, the velocity decreases significantly, and the temperature increases significantly as shown in Figure 3. That is, the heat transfer ability of ternary nanofluid with $\Phi_2 =$ 3% is higher than ternary nanofluids with $\Phi_2 =$ 1% and 2%.

**Case 3:** Effect of volume fraction of $SiO_2$ ( $\Phi_3$ ) on velocity and temperature is studied, it is noticed that the increment in volume fraction leads to a significant

increment in the velocity and decrement in the temperature as shown in Figure 4. That is, the heat transfer ability of ternary nanofluid with $\Phi_3$ = 3% is lesser than ternary nanofluids with $\Phi_3$ = 1% and 2%.

**Case 4:** A comparative study on the influence of different types of fluids (Polymer base, Cu-Polymer, Cu/$Fe_3O_4$ -Polymer, Cu/$Fe_3O_4$/$SiO_2$-Polymer) on velocity and temperature is made, it is observed that Cu/$Fe_3O_4$ -Polymer fluid has higher heat transfer ability than the remaining fluids as shown in Figure 5.

In **Case 1** and C**ase 2,** it is seen that the volume fraction of one type of nanoparticle has a positive impact on the improvement of the heat transfer ability of the ternary nanofluid with a concentration of the other two nanoparticles being fixed. This could be because of the positive interactions between heterogeneous nanoparticles, homogenous nanoparticles, and the polymer base molecules. Whereas in **Case 3** it is seen that volume fraction of $SiO_2$ nanoparticle has a negative impact on the improvement of the heat transfer ability of the ternary nanofluid.

In C**ase 4** at 3% volume fraction, hybrid nanofluid (Cu/$Fe_3O_4$ -Polymer) shows higher heat transfer ability than the other fluids. This could be because of good chemical and physical interactions between nanoparticles and fluid molecules.

## 5.0 Conclusion

The results conclude that an increase in the volume fraction of $SiO_2$ may have a negative impact on the heat transfer ability of the ternary nanofluid (Cu/$Fe_3O_4$/$SiO_2$-Polymer). From the perspective of enhancement of heat transfer ability interactions between nanoparticles and the polymer molecules are better in the case of hybrid nanofluid (Cu/$Fe_3O_4$ -Polymer) than in the case of ternary nanofluid (Cu/$Fe_3O_4$/$SiO_2$-Polymer). Therefore, in general volume fraction of the nanoparticle may have a positive impact on heat transfer ability if there a good chemical and physical interactions between the nanoparticles and the molecules.

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